

NASA Technical Memorandum 58277

Research and Technology

Annual Report 1986

(NASA-TM-58277) RESEARCH AND TECHNOLOGY:
1986 ANNUAL REPORT OF THE LYNDON B. JOHNSON
SPACE CENTER Annual Report (NASA) 73 p
Avail: NTIS HC A04/MF A01

N87-29403

CSCI 05B

Unclas
G3/99 0098659



NASA

National Aeronautics and
Space Administration

Lyndon B. Johnson Space Center

NASA Technical Memorandum 58277

Research and Technology

Annual Report 1986

December 1986

Prepared by
Office of the Director of Engineering
Lyndon B. Johnson Space Center
Houston, Texas

Preface

This report is prepared on an annual basis for the purposes of highlighting the fiscal year research and technology (R&T) activities. Its intent is to better inform the R&T Program Managers of significant accomplishments that promise practical and beneficial program application. The report is not inclusive of all R&T activities. This document will be updated in November of each year.

The JSC Annual R&T Report is compiled by the Office of the Director of Engineering. The personnel listed below have coordinated the technical inputs for their respective sections of the report. Detailed questions may be directed to them or to the technical monitors listed in the Significant Task indices.

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Space Sciences and Applications Life Sciences

Summary

Office of Space Sciences and Applications

Life Sciences

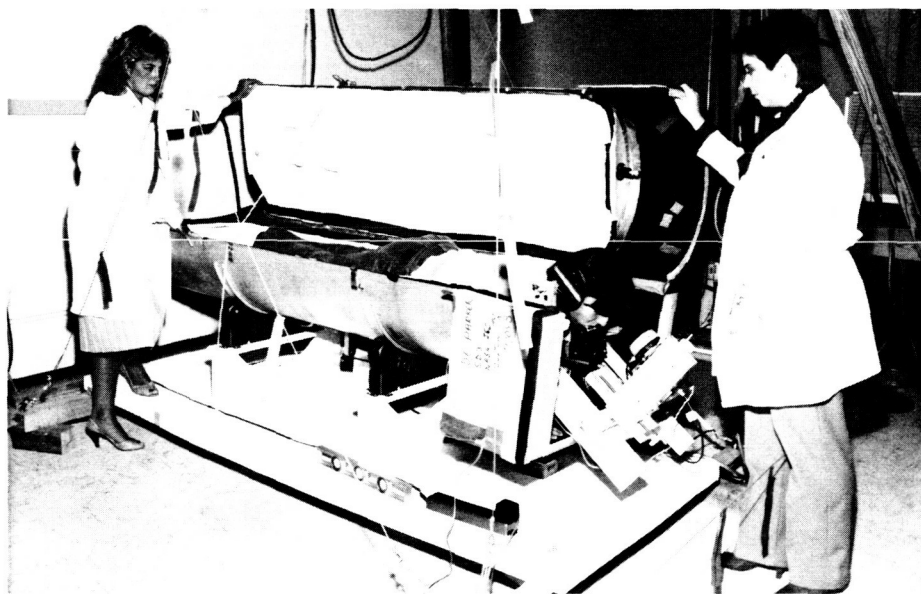
Summary

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In preparation for man's permanent presence in space, researchers at the Johnson Space Center (JSC) are developing guidelines for a high-quality, permanent health care delivery system for the Space Station. The Medical Operations Branch of the Medical Sciences Division is actively pursuing the goal of ensuring the health and safety of the Space Station crews. An active preventive medicine program that includes safety education, emergency medical treatment and contingency procedures, frequent medical checkups before and during flight, in-flight exercise and countermeasures, and a well-designed health maintenance facility (HMF) should help to prepare the crew to cope with environmental hazards.

The design of the Space Station HMF presents a special challenge. Intended to provide preventive, diagnostic, and therapeutic medical care for the crew, the HMF must be designed to meet the unique circumstances and needs of the Space Station in its micro-g environment. Space and weight limitations are primary design drivers. Quick access to medical equipment is another important requirement. A functional analysis currently being conducted will identify high-use and critical-use items so that these may be positioned conveniently for the user. Avoiding obsolescence and continuous resupply are complex problems being addressed to guarantee nearly 100% reliability.

To help differentiate life-threatening problems from self-limiting minor illnesses, the HMF must provide the capability to monitor certain physiological parameters: cardiographic, including arrhythmia detection; blood pressure; respiration; body temperature; and transcutaneous blood gases. Non-invasive cardiac output monitoring is considered desirable. Toward this end, a technique has been developed to permit the estimation of central venous



The parallel swing used to collect preflight and postflight data for DSO's 433 and 439.

pressure without the discomfort and inconvenience of venipuncture. Also, a complete "crash cart" capability is planned and will include a defibrillator with adhesive electrode and external pacer, a bag-valve-mask, and a set of cardiac/trauma drugs and accessories.

All treatment and patient monitoring equipment will feed data back to the HMF medical computer. A medical decision support system (MDSS) is being developed to provide computer assistance. The MDSS will provide an integrated medical information management system for the HMF. The system will have preventive, diagnostic, and therapeutic computer-assisted medical management, algorithms, checklists, procedures, and indexed medical reference materials as well as computer-assisted inventory management of medical supplies and pharmaceuticals. All the information collected by the MDSS will be downlinked regularly to the NASA flight surgeon and to ground-based medical consultants.

In addition to the treatment and monitoring equipment, a medical analytical laboratory will be onboard the Space Station as a subsystem of the HMF. The constraints imposed by the unique Space Station environment necessitate that instrumentation be evaluated for clinical performance, fluid handling, sample requirements, reagent stability, and other factors which could be influenced by micro-g. To meet these requirements, a comprehensive instrument evaluation program addressing these factors was undertaken.

Along with the HMF work, ground-based and flight research programs are being continued. To help in understanding space adaptation syndrome (SAS), a lightweight helmet with electronic sensors and stimulators has been constructed for use in micro-g vestibular investigations. To aid the researchers in obtaining microvolume blood samples, a kit containing tools that permit rapid and precise aliquoting and distribution of small-animal blood samples has been fabricated.

Ground-based studies simulating space flight are being conducted to investigate the extent and rate of trabecular and cortical bone loss as well as the rate and degree of recovery. A new piece of equipment, the Osteo-Analyzer, a prototype of which was used on Skylab missions, is being used to investigate bone demineralization.

The problem of decompression sickness ("bends") has been of concern to NASA. Past experiments at JSC have shown that increased duration of 100% O₂ prebreathing decreases the incidence of decompression sickness symptoms and venous gas emboli (bubbles in the pulmonary artery). Experiments to elucidate the dynamics of this washout process have been conducted on 19 individuals of both genders for 51 runs.

Many of the ground-based and flight research programs have been supplemented by in-flight medical research performed under the Detailed Supplementary Objective (DSO) Program of JSC. The DSO is a mechanism for the study of operational problems, including medical problems, the solutions of which are of vital importance to Space Shuttle operations. Candidate investigations are extensively reviewed by the Life Sciences Directorate and Space Transportation System (STS) boards and committees before they are finally manifested on a particular mission. Medical DSO's have been a part of many Space Shuttle flights to date; more than 50 DSO's have been flown on the Space Shuttle. A large number of these investigations occurred on Space Shuttle flights STS-8, STS 51-D, and STS 61-C.

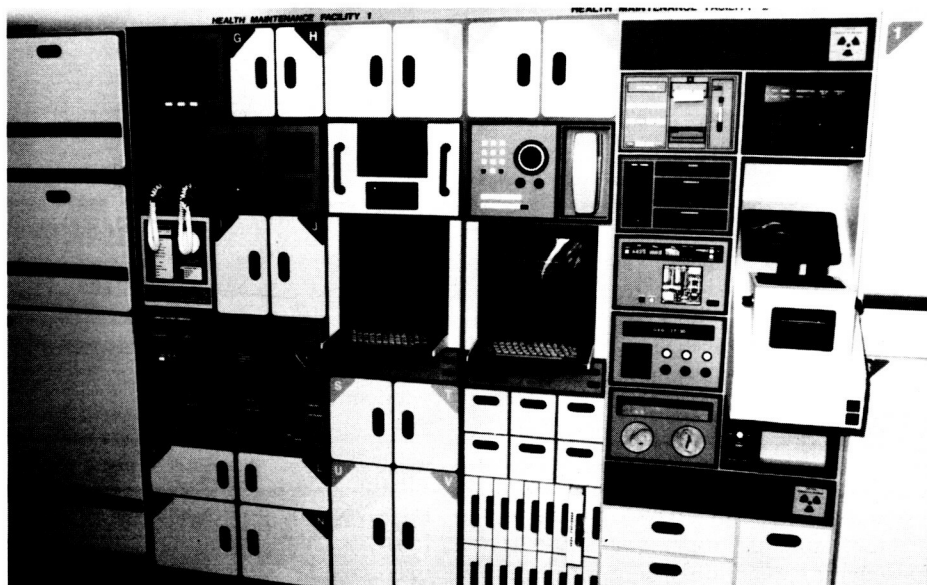
Some investigations (such as 403 and 404) revealed no abnormalities in neurophysiological function even though abnormalities had been predicted. Others have demonstrated interesting and somewhat unexpected findings. For example, DSO 433 revealed that, during the early postflight period, passive tilting of the crewmember's head produces a perception of linear translation. Surprisingly, DSO 459 showed that ocular counterrolling could be produced in flight but to a lesser degree than on the ground.

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In-flight data collection with the ocular counterrolling goggles (DSO 459).

Health maintenance facility display panel.



Space Sciences and Applications Life Sciences

Significant Tasks

Considerations in the Design of a Health Maintenance Facility for the Space Station

TM: James S. Logan/SD2

PI: Mary M. Jurmain/SD2

Reference OSSA 1

The NASA Space Station Program differs from previous manned space programs in that it represents the beginning of man's permanent presence in space. Crews will live and work in the Space Station for months at a time, and considerable research and activity is being devoted to making the facility as habitable and as comfortable as possible.

The design of the Space Station health maintenance facility (HMF) presents a special challenge. Intended to provide preventive, diagnostic, and therapeutic medical care for crewmembers during missions, the HMF must be designed to meet the unique circumstances and needs of the Space Station and its zero-g environment.

Space limitation is a primary design driver. The HMF equipment (excluding exercise devices) is expected to occupy two 42-in. equipment racks. This space limitation will require miniaturization and repackaging of equipment and subsequent detailed safety, reliability, and quality assurance analyses to ensure that the repackaged equipment will meet all requirements.

Current plans are to place the HMF in the habitation module, where the crew will live and perform basic Space Station operations. With the recent decision to eliminate two modules from the Space Station design, space availability is even more critical. The team designing the HMF is currently considering a configuration that would permit the HMF to share space with the exercise equipment area and that would remove the patient restraint device from a high-traffic area. (The patient restraint device combines the functions of stretcher, hospital bed, and treatment table.)

Quick access to medical equipment is another important requirement. A functional analysis being conducted will identify high-use and critical-use items so that these may be positioned conveniently for the user. It should be noted, however, that access to items in zero g may differ from that on Earth, since translating in zero g may permit easier access to highly placed items.

Exercise will be particularly important for preventive health care onboard the Space Station. The zero-g environment causes a decrease in cardiovascular fitness, muscular strength, and immune response. Regular exercise can mitigate this deterioration.

Since preparation for and cleanup after exercise can take 30 min or longer, and crewmembers will have many other activities to perform, adhering to a regular exercise schedule presents a challenge. Thus, crewmembers must be motivated to use the exercise equipment. Members of the HMF design team are designing computer software that will help exercising crewmembers monitor their own progress and compete with other crewmembers if they wish.

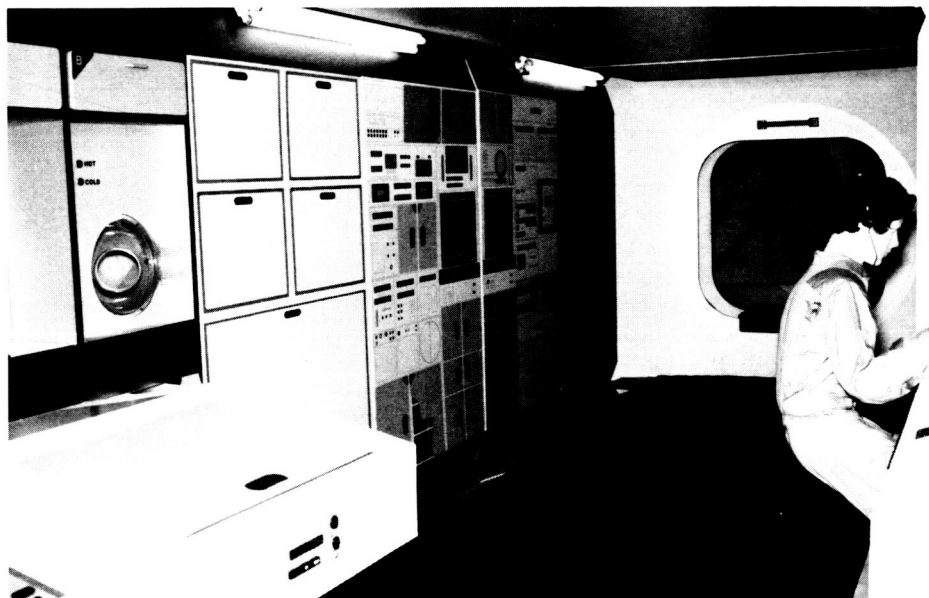
Although the Space Station is expected to have some physicians as crewmembers, a physician may not be aboard at all times. The availability of a quick rescue vehicle has not been determined. Performing medical procedures in zero g will require new techniques and skills. Therefore, crewmembers must be trained carefully, and the HMF must be designed such that nonphysicians can operate it. Central computer access will simplify some procedures, but equipment also must retain the capability of independent operation and, in some cases, be transportable to other areas of the Space Station or to a rescue vehicle.

Design of the Space Station HMF presents an enormous challenge but also promises the satisfaction of setting precedents in space medical care that will endure for many years.

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Inside view of habitability module.



Treatment Capabilities for Space Station Health Maintenance Facility

TM: James S. Logan/SD2
PI: Michael F. Stolle/SD2
Reference OSSA 2

The existence of a permanently manned Space Station, extended periods of living in space, reduced criteria for personnel selection, and limited rescue capability present unique medical problems. A dedicated health maintenance facility (HMF) is therefore an essential medical capability.

A set of premises was established to determine treatment capabilities to be included in the HMF. First, planned rescue capability is for a maximum response time requirement of 45 days. Second, only one critically ill crewmember will be treated at any one time. Third, off-the-shelf medical equipment will be used as much as possible. Fourth, the most likely illnesses expected to be encountered onboard Space Station, and the needed treatment capability, must be considered. Fifth, some illnesses are expected to have low probabilities of occurrence, but treatment capability for them must exist. Sixth, current program guidelines do not assure that a physician is always present.

Based on these premises, it was determined that certain physiologic parameters must be monitored: cardiographic, including arrhythmia detection; blood pressure; respiration; temperature; and transcutaneous blood gases. Noninvasive cardiac output monitoring is considered desirable. A complete "crash cart" capability is planned and will include a defibrillator with adhesive electrodes and external pacer, a bag-valve-mask, and a set of cardiac/trauma drugs and accessories.

In addition, a complete pharmacy and central supply facility is planned. The pharmacy will contain nonprescription and prescription drugs and will provide adequate drug control and patient record update through communication with the HMF medical computer. All treatment equipment and patient monitors will feed data to the HMF medical computer.

Infusion of drugs and fluids will be provided with pumps to infuse solutions made from rehydrated packages of saline, lactated Ringer's, etc. Pulmonary and oxygen therapy will be delivered

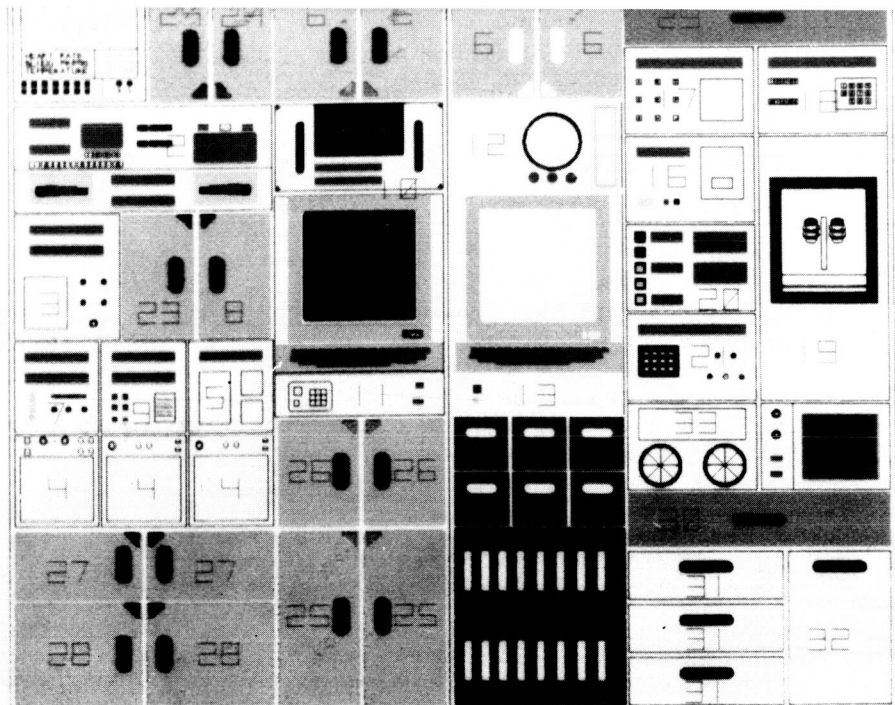
by means of a fully controllable ventilator. Medical antishock trousers (MAST's) will be included as part of the trauma treatment section. Control of body fluids and secretions in a weightless environment will require use of an aspirator, sponges, and collection bags.

In addition to medical equipment, a system is provided to restrain the patient during procedures and to provide stability to the medical officer so that no conscious effort to maintain position is required. Lastly, since decompression sickness is a possibility for humans living and working in a vacuum, a hyperbaric treatment facility is planned.

Transportation of the patient and of necessary medical life support equipment has been a major consideration. A complete transport pack for a Space Shuttle rescue mission is planned. This transport pack will consist of a patient monitor, a defibrillator and cardiac/trauma pack, MAST's, an aspirator, a transport computer (with patient record input), a ventilator, an intravenous (IV) system, and the patient restraint system.

Many vendors of commercial equipment provide these medical capabilities. A set of decision criteria was selected to determine, using tradeoff studies, equipment that best meets the requirements. Based on these criteria, the most appropriate hardware to provide the quality of care necessary aboard the Space Station will be selected.

Conceptual on-orbit HMF module.



HMF FRONT FACE

- | | |
|---|---|
| 1. PATIENT MONITOR | 17. HEMATOLOGY |
| 2. HYPERBARIC & TRANSPORT PACK | 18. INVENTORY CONTROL |
| 3. VENTILATOR/PULMONARY FUNCTION ASSESSMENT | 19. DIGITAL MICROSCOPE |
| 4. IV PUMPS | 20. BLOOD GASES |
| 5. SUCTION | 21. MICROBIOLOGY |
| 6. CENTRAL SUPPLY | 22. INCUBATOR |
| 7. CARDIAC OUTPUT MONITOR | 23. AIRWAY SUPPLIES |
| 8. FLUID THERAPY | 24. LIFE SUPPORT, CRITICAL CARE, & MONITORING INSTRUMENTATION |
| 9. AIR/FLUID SEPARATION | 25. PHARMACY |
| 10. CRASH CART DEFIBRILLATOR | 26. DENTAL INSTRUMENTS |
| 11. COMPUTER | 27. IV FLUID PRODUCTION |
| 12. MEDICAL COMPUTING/COMMUNICATION | 28. IV FLUID RECONSTITUTION |
| 13. COMPUTER | 29. XRAY SOURCE |
| 14. PHYSICIAN'S INSTRUMENTS | 30. XRAY IMAGE RECEPTOR |
| 15. PHYSICIAN'S INSTRUMENTS | 31. SUPPLIES & EQUIPMENT |
| 16. CHEMISTRY | 32. BIOLOGICAL WASTE DISPOSAL |
| | 33. GLOVE BOX |

Computerized Medical Decision Support for the Space Station Health Maintenance Facility

TM: James S. Logan/SD2

PI: David V. Ostler/SD2

Reference OSSA 3

A medical decision support system (MDSS) is being developed to provide computer assistance to medical officers on NASA's Space Station in conjunction with the health maintenance facility (HMF). The Space Station will have medical care requirements beyond those of previous space systems. The Space Station will have 90-day missions with resupply by the Space Shuttle at 30- or 60-day intervals. Space Station medical officers may not always be physicians. As a minimum, two paramedic-trained astronauts will be designated as Space Station medical officers.

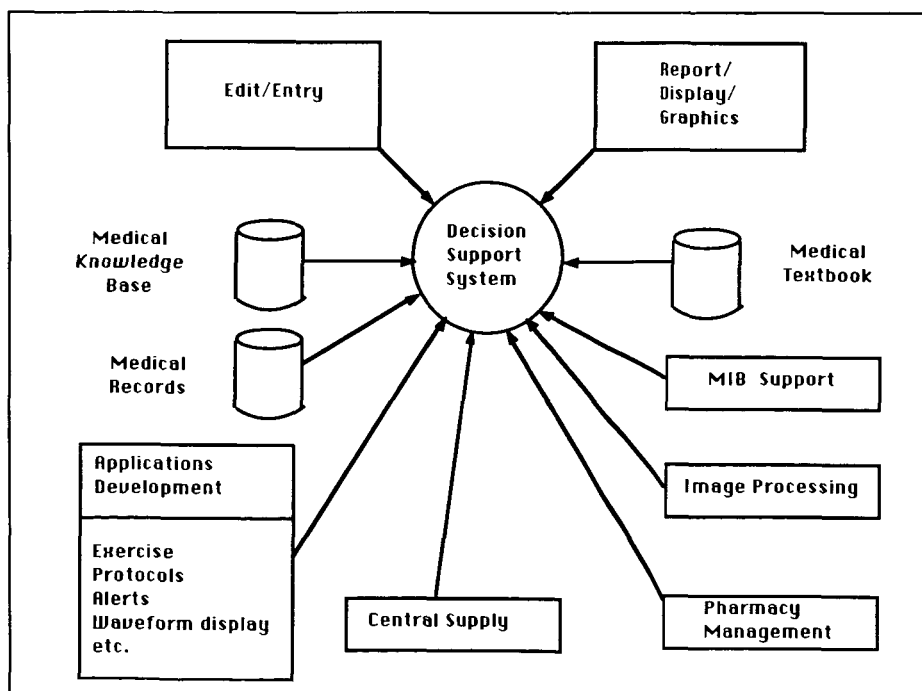
The MDSS will provide an integrated medical information management system for the HMF. The system will have preventive, diagnostic, and therapeutic computer-assisted medical management algorithms; computer-assisted medical checklists, procedures, and indexed medical reference materials; and computer-assisted inventory management of medical supplies and pharmaceuticals. Through Space Station services, the MDSS also will support the exchange of electronic mail between any crewmember and the ground-based crew surgeon and will support secure two-way voice communications among crew medical officers, NASA flight surgeons, and ground-based medical consultants. Additionally, all information collected by the MDSS will be downlinked regularly to the NASA flight surgeons and to ground-based medical consultants. Each HMF subsystem will provide peripheral processing of real-time data measurements. Thus, each subsystem will transmit processed and verified measurements and information to the MDSS.

Sampled waveform data will not be stored in the MDSS onboard the Space Station but will be transmitted to the ground for research purposes. The medical information bus (MIB), under development by an MIB working group, is specified as the communication medium between the MDSS and HMF subsystems. Data from the subsystems will be recorded automatically in medical records maintained by the MDSS. Design around a standardized MIB will enable substitution of new clinically validated instruments for the instruments initially provided in the HMF.

The MDSS will have an integrated kernel of system services. A medical records system will provide a complete record of each crewmember's medical history, a record of all physiological measurements, and a record of medical notations made by the medical officer while on the Space Station. A medical knowledge base will be created to provide medical protocols for diagnosis, treatment, and medical record processing support. An electronic medical textbook will be created by selecting and extensively indexing medical texts for reference material on the Space Station. The MDSS will use the hardware elements developed for the Space Station data management system, a distributed network of redundant processors and mass storage devices that will provide common data base management support and ground communications support for the Space Station.

MDSS applications will use the kernel services to allow entry of information into the medical record, text and graphic display of information from the medical record, radiological image display, and specific medical protocol implementation. In addition to the medical protocol support, the MDSS will provide communications to a ground network of medical specialists in the event of major medical contingencies. Protocols, algorithms, and systems used in the MDSS will be the predecessors of those needed to provide medical care for future long-duration space flight.

Functional block diagram of the HMF medical decision support system.



Mechanical Ventilation for Medical Patients Aboard the Space Station

TM: James S. Logan/SD2
 PI: Bruce A. McKinley/SD2
 Dwayne R. Westenskow
 Reference OSSA 4

Assistance in breathing is commonly required by medical patients with severe cardiorespiratory disease. Breathing can be assisted by means of a ventilator, an electromechanical instrument, to supply oxygen and to remove carbon dioxide through a breathing tube and circuit connected to the patient's trachea. Disease states that may require mechanical breathing assistance aboard Space Station could include several categories of injury and illness.

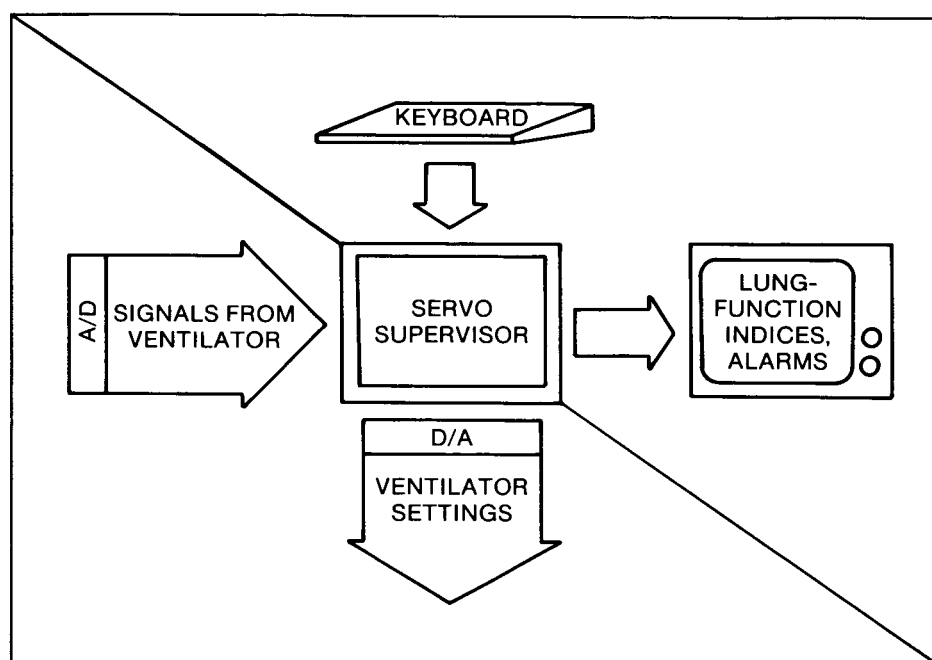
Whereas proper and timely use of mechanical ventilatory support could save a patient's life, the appropriate instrumentation and apparatus must be available to permit mechanical ventilation in the Space Station setting and, if needed, during transport from the Space Station to Earth. This equipment is being selected, tested, and developed as a component of the Space Station health maintenance facility (HMF).

Several mechanical ventilators are available for use in hospitals. Some of these instruments are sufficiently compact and lightweight to be used during patient transport. Accurate monitoring and control of the patient and the instrument also are required during mechanical ventilation. For Space Station, medical monitoring is intended to be supplied at the instrument, at an onboard medical computer, and at ground-based medical consultant terminals. The Siemens model 900C ventilator was selected for initial design efforts because of its compact pneumatics system, its low electrical power requirements, its modularity, and other advantages.

A system to provide complete mechanical ventilatory support and monitoring (on site and at consultant remote terminals) is being designed by bioengineers at the University of Utah. Information from the ventilator is monitored constantly to provide a continuous record of ventilatory status and of lung function parameters that indicate changes in ventilatory support effected manually by the onsite medical attend-

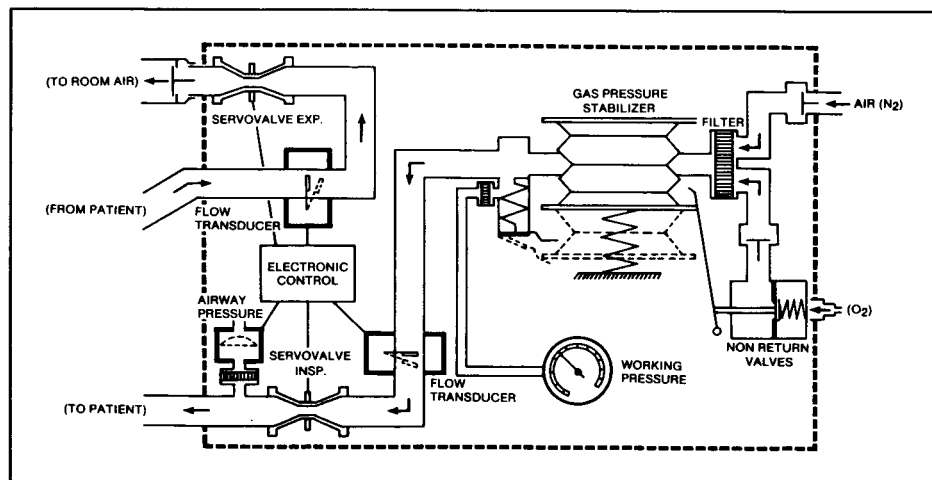
ant. A second major function of the system under development is to indicate changes in patient ventilatory status, to provide warnings indicating parameters of concern, and to provide integrated analysis and backup of instrument alarms to assist the remote consultants in advising and the onsite medical attendants in adjusting appropriate ventilator controls. The pneumatics unit of the Siemens 900C ventilator and data flow from the ventilator electronics module to various monitoring sites are illustrated.

Hardware related to mechanical ventilation of a patient includes breathing circuits, endotracheal tubes, and instruments to permit correct positioning of an endotracheal tube in the patient's airway. Supply of oxygen and air (or nitrogen) to the ventilator instrument at appropriate pressures is also required and is planned to be from Space Station respirable atmosphere supplies. Capability for manual ventilation when using a bag-valve-mask assembly also is being planned.



Space Station HMF mechanical ventilator system data flow.

Siemens 900C pneumatics unit.



Dynamics of Whole-Body Nitrogen Washout While Breathing 100% Oxygen

TM: David J. Horrigan, Jr./SD5

James M. Waligora/SD5

PI: John H. Gilbert III/SD5

Benjamin F. Edwards, Jr./SD5

Reference OSSA 5

Past experiments at the Johnson Space Center (JSC) have shown that increased duration of 100% oxygen (O_2) pre-breathing decreases the incidence of decompression sickness symptoms ("bends") and venous gas emboli (bubbles in the pulmonary artery). Experiments to elucidate the dynamics of this washout process have been conducted at JSC over the past 2 yr.

The recent experiments involved the use of 11 male and 8 female test subjects, who breathed 100% O_2 from a sealed mask for 210 min in each of three body positions: (1) sitting, (2) supine, and (3) supine with a 6° head-down whole-body tilt. Measurements of incremental breath volume and corresponding instantaneous nitrogen (N_2), O_2 , and carbon dioxide (CO_2) breath fractions during the entire respiratory cycle were made using a computer-controlled mass spectrometer. Respiratory tidal volume and average breath N_2 , O_2 , and CO_2 percentage measurements were recorded at the end of each breath. Analysis of these data gave the total volume of N_2 expired during each breath and the total N_2 volume eliminated during the procedure. This information was combined with previously measured and/or calculated physical parameters.

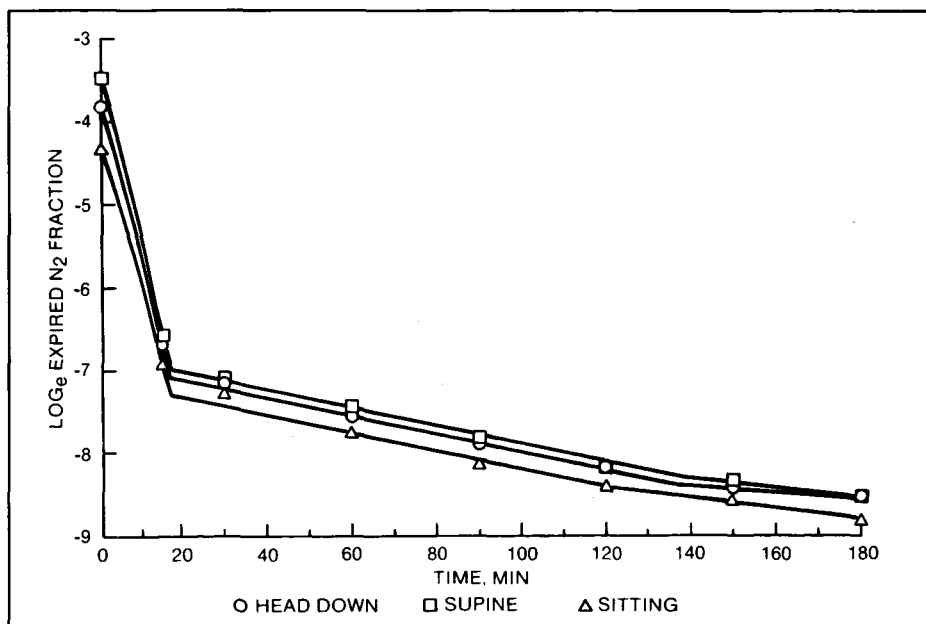
Statistical analyses on 51 runs of the 19 individuals in the various body positions suggest gender- and position-related differences in N_2 washout rates (ml/min) and/or fraction of the expired gas (N_2). With a 3-by-2 analysis of variance (ANOVA) (three positions, two genders), N_2 washout rates were not affected by position but were significantly different throughout the experiment between males and females, with females having lower rates. Significant differences in N_2 expired gas fraction were seen, however, throughout the 90-min interval between both gender and position levels. Gender/position interaction was significant only at the 15-min interval. Total N_2 volume washed out during the run is also significantly lower in females than in males.

When a contrast analysis of the position data is performed on the N_2 expired gas fractions, significant differences are seen between the sitting and supine positions through 90 min, but no differences are noted in comparisons of sitting and head-down positions or of supine and head-down positions. (See figure.) A significant difference also seen at 15 min between supine and head-down positions suggests that cephalad movement of the viscera may be affecting respiratory efficiency leading to altered tidal volumes.

When the N_2 expired gas fraction or the N_2 washout rates were graphed over time, a three-phase exponential curve was seen. The slopes of each phase were compared by means of the 3-by-2 ANOVA. The first phase generally ended at about 20 min into the washout, and the second phase ended at about 80 to 90 min. The third washout phase asymptotically approached a constant washout rate or fraction, and no rigorous equation could be derived to describe it. The slopes of these phases were not significantly different when gender or body position were compared.

Regression computed using N_2 washout rates compared to total body water, average tidal volume, vital capacity, and total body fat mass revealed the closest correlation with total body water ($r = 0.85$). When graphed, these data points showed gender-oriented washout rates as falling upon a continuous line with data from female subjects around the lower end of the spectrum and data from males at the upper end. This observation would explain the consistent and significant differences between male and female washout rates and expired volumes described previously and also explains the lack of differences between the slopes of the exponential washout curves when they were graphed as natural logarithms. This finding implies that the physiological processes involved in the washout process are not gender dependent. The differences seen in washout rates are most likely dependent only on body-size-related parameters.

Position-related expired N_2 fraction (combined data from male and female subjects).



Clinical Laboratory Capability for the Health Maintenance Facility

TM: Bernard J. Mieszkuc/SD4

PI: Karen Gaier/SD4

Reference OSSA 6

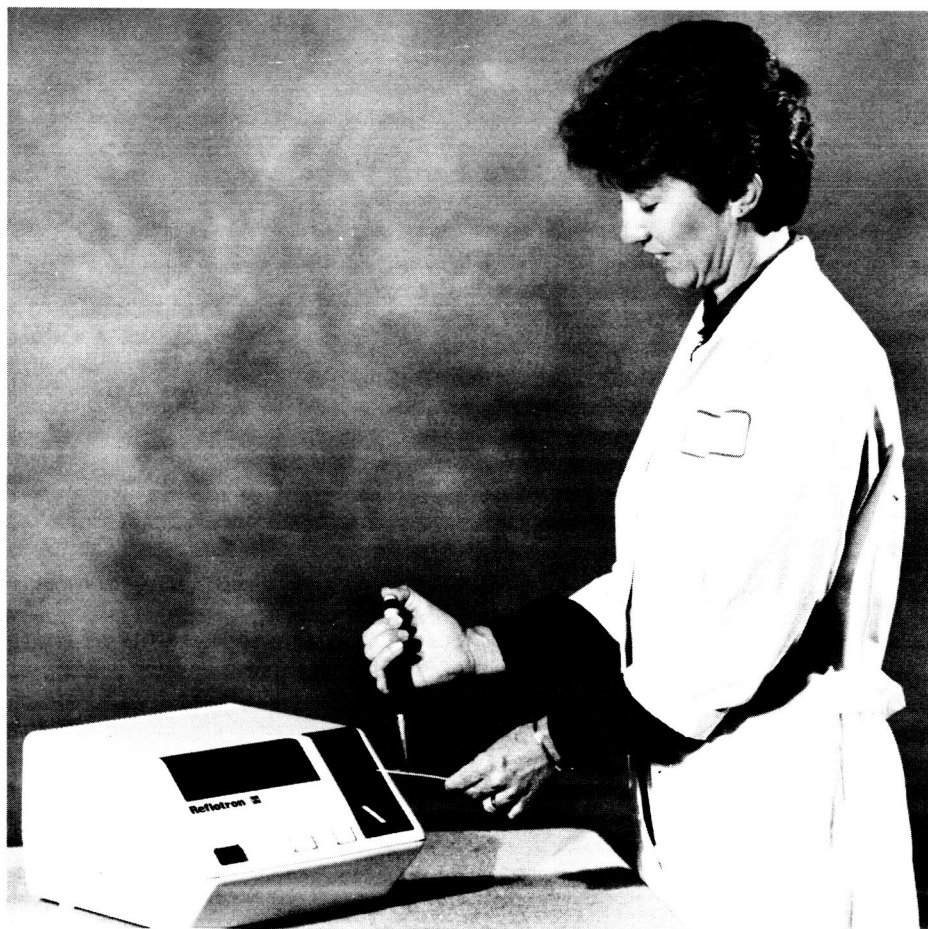
The Space Station represents the beginning of man's permanent presence in space. A system for in-flight health care and maintenance is essential for the success of the program. The health maintenance facility (HMF) will provide in-flight preventive, diagnostic, and therapeutic capabilities within the Space Station. One of the major subsystems of the HMF is the medical analytical laboratory, which will provide in-flight analytical capability to facilitate medical diagnosis and to guide appropriate therapy. Some of the components of this subsystem include blood/urine chemistry, hematology, and microbiology.

One of the guidelines for the development of the HMF is that off-the-shelf instrumentation be used where applicable because of proven analytical performance and reduced developmental costs. The constraints imposed by the unique Space Station environment necessitate that instrumentation be evaluated for clinical performance, fluid handling, sample requirements, reagent stability, and other factors which could be influenced by micro-g. Additionally, factors not influenced by micro-g, such as size, weight, and power specifications, must be considered.

A comprehensive instrument evaluation program addressing clinical performance, human factors, reagent requirements, and micro-g compatibility was undertaken. Specifically, clinical performance evaluation includes instrument precision, linearity, accuracy, calibration requirements, and correlation with standard methods. Human factors include maintenance, ease of operation, technician prompts, and troubleshooting and repair. Reagent requirements take into account storage, preparation, liquid handling, and shelf life. Micro-g compatibility considers the mechanical and analytical operation of the instrument in micro-g.

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Technician evaluating a clinical chemistry analyzer.



Processing Kit for Microvolume Blood Samples

TM: Philip C. Johnson/SD

PI: Theda Driscoll/SD4

Ron Nachtman/SD4

Reference OSSA 7

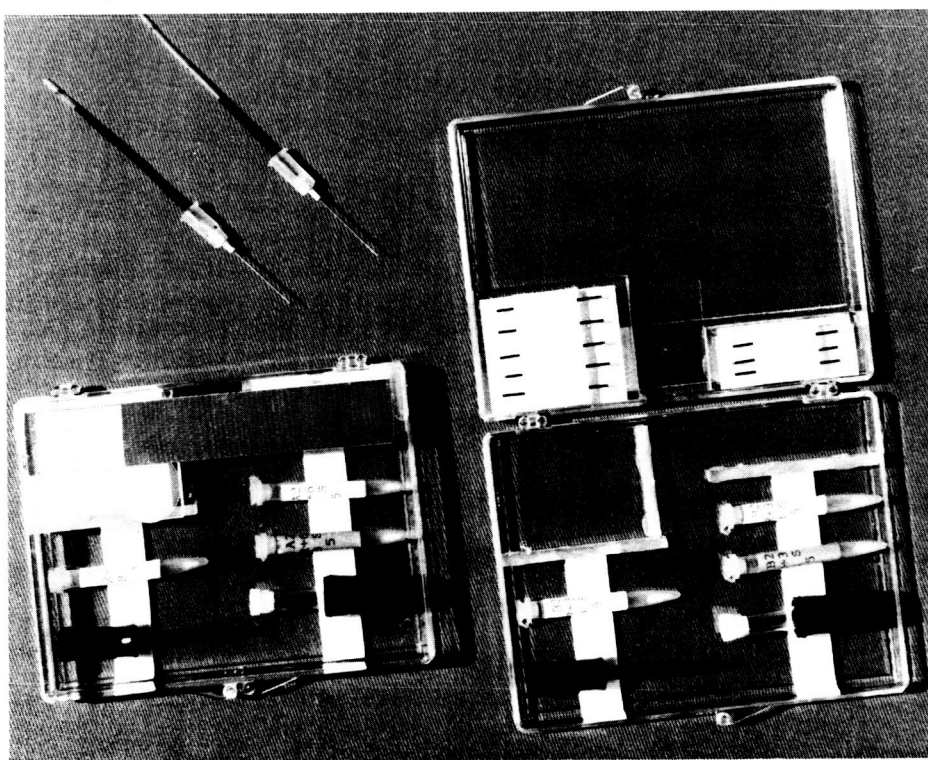
Researchers working with small animals are restricted to microvolumetric sequential blood samples to prevent affecting the animal's hematology and chemistry values. These small blood samples must be processed immediately after they are obtained because of their rapid loss of moisture. Manipulation of the glass micropipettes used in obtaining volumetric samples is difficult because they are small and fragile. As a solution to these problems, a kit containing tools that permit rapid and precise aliquoting and distribution of small-animal blood samples has been developed. Small boxes, originally designed for cosmetics, were modified for hematology work, resulting in kits for processing one or two microvolumetric blood specimens. These 117-by-90-by-10.5-mm kits are prepackaged, color coded for easy animal subject identification, and labeled with the date of the experiment. The transparent boxes show the number and type of hematology and chemistry samples collected and aliquoted after a single blood draw.

Inside the kits, 10- μ l micropipettes are sandwiched between Velcro strips attached to elevated platforms. This arrangement allows each blood specimen to be aliquoted efficiently into micropipettes, which are later removed for processing. In addition to micropipettes, the kits contain a micropipette holder, for safe handling and manipulating of the pipette; a blowout bulb, for transferring blood samples into diluting and staining fluids; and pre-labeled, color-coded miniature test tubes, to ensure proper sample identification in preparation for various analyses. The kit is large enough to accommodate additional micropipettes, miniature test tubes, capsules with reticulocyte stains, etc., depending on the requirements of a particular experiment. Because of the ease with which processed samples and disposables can be replaced, use of the kits is highly practical in space-flight animal experiments.

The kits, as configured in the photograph, were used recently to collect samples for two consecutively timed phlebotomies of 50 and 30 μ l, which yielded eight 10- μ l blood samples from a single laboratory animal. These types of kits presently are used in the ground research of life sciences experiments 012 and 141, which are to be flown on the first Space Life Sciences Space Shuttle mission.

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Processing kit for microvolume blood samples. Dimensions of the closed kit are 117 by 90 by 10.5 mm. This compact box contains items for aliquoting, transferring, and storing multiple blood samples obtained from small laboratory animals.



OsteoAnalyzer

TM: Philip C. Johnson/SD

PI: Adrian D. LeBlanc/SD5

Reference OSSA 8

A number of physiological changes occur in humans subjected to the space environment. Among these changes is bone mineral loss. Bone demineralization is of concern because reduced bone mass is recognized as the most important factor in the etiology of osteoporosis. Bone mineral loss was not considered clinically important in U.S. space flights of 3-month duration; however, it is of concern in more extended or repeated space flights.

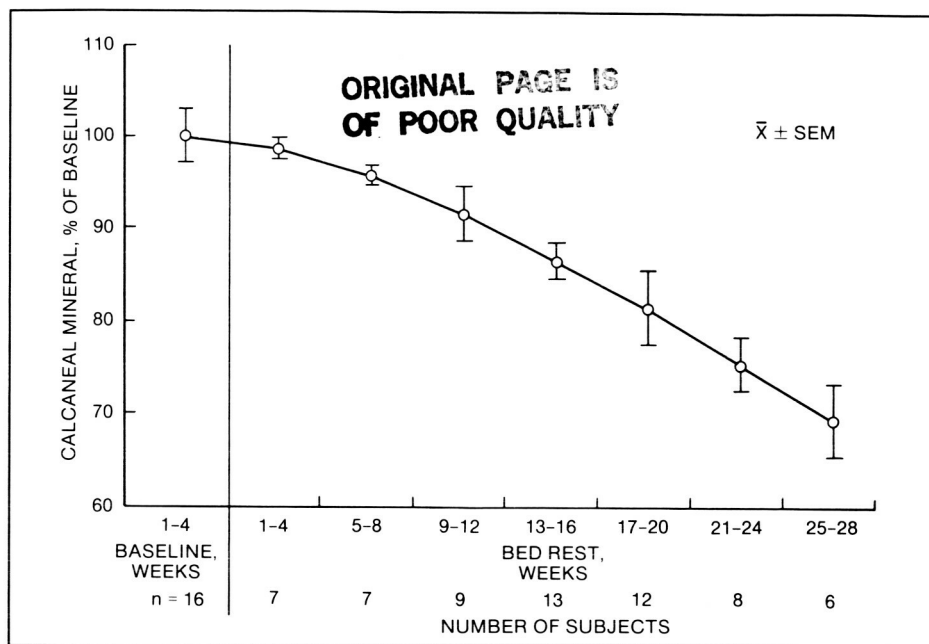
The body contains two basic types of bone, cortical and trabecular. Cortical bone is compact, found largely in the long bones of the body, and requires about 15 yr for complete turnover. Trabecular bone, however, is the force-bearing structural support type of bone found typically in the spine, the heel, and the forearm. This second type of bone requires about 5 yr for complete turnover. Bone loss associated with aging osteoporosis appears to affect trabecular bone before it affects cortical bone. Therefore, it seems more advantageous to screen for early bone loss by measuring trabecular bone changes. However, since some therapies result in building trabecular bone at the expense of cortical bone, measuring cortical bone is necessary also.

The new OsteoAnalyzer, a prototype of which was used on Skylab missions, is being used to investigate bone demineralization. A self-contained mechanical scanner, equipped with power supply and specially configured microcomputer, helps researchers determine bone mineral content noninvasively, in vivo, with a radiation exposure less than that of a single chest X-ray. The versatility of the OsteoAnalyzer allows a wide range of measurements of both cortical and trabecular bones. It is expected that with this information, a better understanding of the processes leading to osteoporosis can be achieved.

Ground-based studies simulating space flight are being conducted to investigate the extent and rate of trabecular and cortical bone loss as well as the rate and degree of recovery. A large normative data base has been developed in collaboration with investigators at the

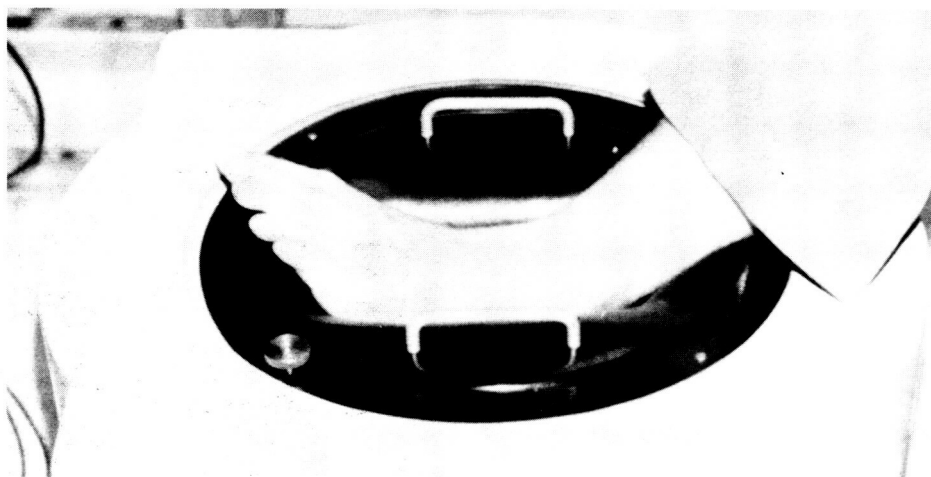
University of Texas Medical School, at Baylor College of Medicine, and at Texas Woman's University for use in NASA's longitudinal studies. Histomorphometric studies are being conducted along with bone mineral measurements to develop an understanding of the mechanisms involved in space-flight-induced bone loss. Although the fundamental process underlying changes in bone during space flight is poorly understood, investigations of countermeasures to prevent or to reduce bone mineral loss are ongoing, including those using low-dose fluoride ingestion and exercise.

The graph shows the decrease in mineral content of the heel bone during 28 wk of bed rest. Bed rest is used in bone research studies because the decrease in skeletal mineral over time may be similar to the losses of bone mineral observed during prolonged space flight. After 6 months of inactivity in bed rest, the subjects lost 30% of the bone mineral in the heel bone. Bone mineral relates to the density of a bone, and loss in bone mineral can be equated to loss of bone. Clinically significant osteoporosis occurs when an individual loses 20% to 30% of the bone mineral.



Decrease in mineral content of the heel bone during 28 wk of bed rest.

The OsteoAnalyzer being employed to assess bone mineral content of a subject's foot. Bone mineral measurements help in understanding the mechanisms involved in space-flight-induced bone loss.



Helmet for Vestibular Investigations Aboard Spacelab

TM: Millard F. Reschke/SB5

PI: Mary Catherine McStravik/SB5

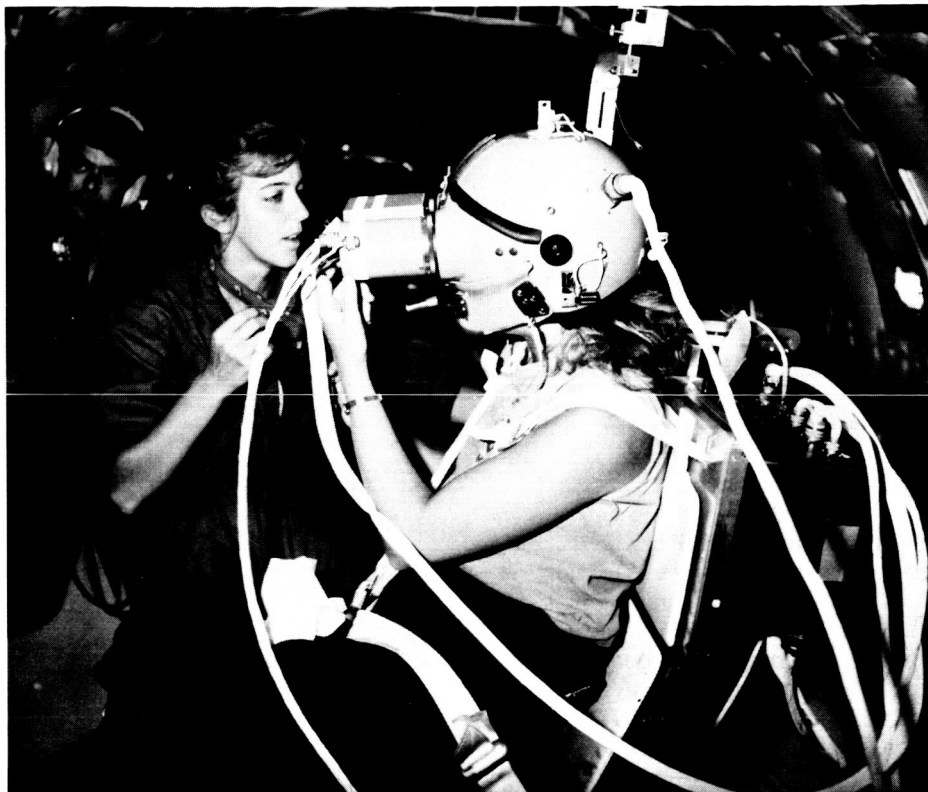
Reference OSSA 9

A lightweight helmet with an array of electronic sensors and stimulators has been constructed for use in micro-g vestibular investigations to study space adaptation syndrome aboard Spacelab. The subject wearing this helmet sits in a rotating chair, which provides the vestibular stimuli. A restraint device attached to the chair confines the head motion to X-, Y-, or Z-axis. A light-tight dual independent visor system permits either or both eyes to be visually stimulated or recorded. Stimulation or monitoring of the eyes is accomplished by modular attachments to these visors.

A camera locked into place on the helmet visor records torsional eye movements. One of the subject's eyes is covered with an opaque contact lens marked with a line. This line allows the investigator to compute the subject's eye movement since the contact lens moves congruently with the eye. The lens also blocks out visible light and fixation points. The movements of the video-recorded eye are synchronized with the opposite eye, which is exposed to various visual stimuli. In addition to the camera, optokinetic and light-emitting-diode modules are also attached to the visors. Instrumentation in these modules is used to measure the subject's horizontal and vertical eye movements (right to left and up and down). The linear orthogonal accelerometers on the helmet indicate translational rotation of the head about the orthogonal axes (pitch, roll, and yaw). The helmet is stabilized on the subject's head with inflatable liners and a bite-board assembly. The biteboard assembly consists of the mouthpiece, the mouthpiece connector, and the assembly's quick-disconnect fitting. This assembly is designed for rapid removal in case of space motion sickness.

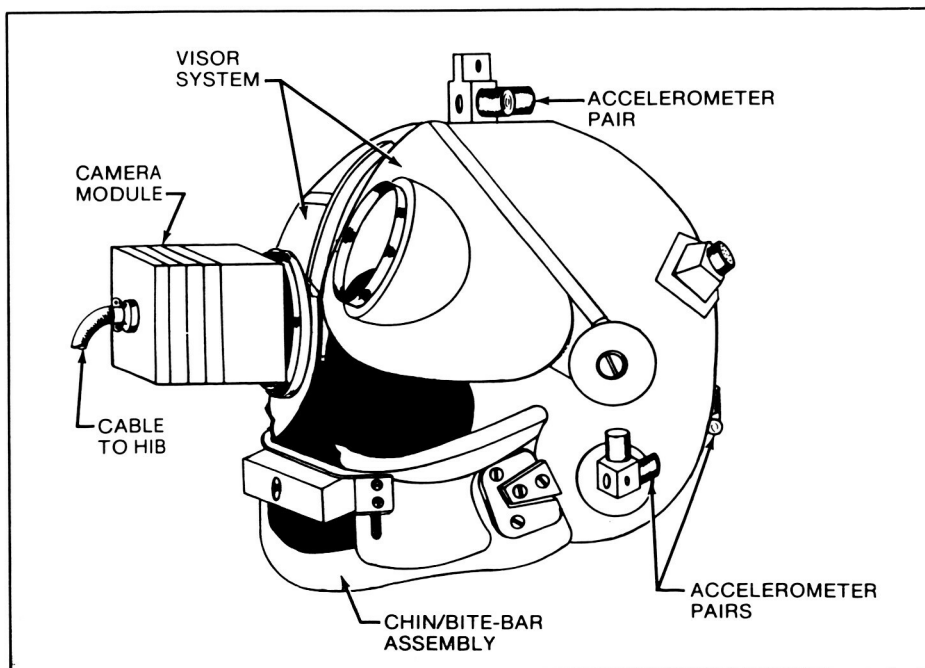
Mounted on the back of the rotating chair is the helmet interface box that supplies power to all of the electronic modules. This unit also includes cables and connectors that transmit output analog signals. The signals from the

sensors are amplified, conditioned, and sent to the computer for formatting. This helmet is scheduled for flight on the first In-Flight Medical Laboratory Space Shuttle mission.



The helmet being tested on a subject flying in the KC-135 aircraft equipped to fly reduced-gravity parabolas.

Drawing of the helmet with its array of electronic sensors and connectors.



Validation of Noninvasive Means of Measuring Central Venous Pressure in Humans

PI: J. B. Charles/SD5
Reference OSSA 10

Exposure to micro-g is associated with cardiovascular changes in space-flight crewmembers. Such changes as headward shift of the body fluids and elimination of the intravascular hydrostatic pressure gradient act to reduce an individual's orthostatic tolerance. These changes are referred to as cardiovascular deconditioning. On return to Earth's gravity, an upright individual is less able to counter the increased hydrostatic pressure. The reduced plasma volume, diminished smooth muscle tone, and impaired reflex responses limit the development of adequate blood pressure for cerebral perfusion with a possible result of orthostatic intolerance.

Because a large part of cardiovascular adaptation to micro-g results from the fluid shifts, an understanding of the cardiovascular and neurohumoral effects of micro-g must begin with a knowledge of the provocative stimuli for these changes. A clinically useful indicator of cardiopulmonary blood volume is central venous pressure (CVP), which reflects the functional state of the heart. This parameter is usually determined from direct measurements of blood pressure in the vena cava at the level of the right atrium, using a long catheter which has been threaded through a vein in the arm or neck. However, to be widely applied in studies on Earth and during space flight, a technique with less operational impact than that of venous catheterization is required.

Recently, a technique has been developed to permit the estimation of CVP without the discomfort and inconvenience of venipuncture. This method involves monitoring the venous blood flow in a jugular or antecubital vein while the subject's intrathoracic pressure is varied until the venous flow is

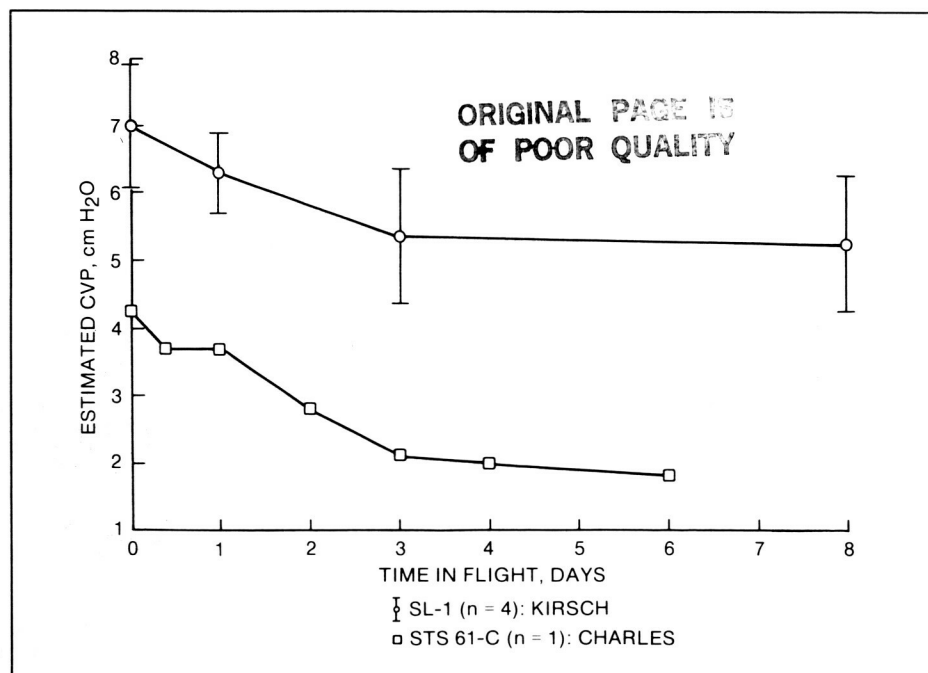
transiently interrupted. Intrathoracic pressure is increased by imposing a slight, variable, end-expiratory airway resistance via a mouthpiece. The

pressure generated within the mouthpiece can be related to intrathoracic pressure; the pressure that transiently stops venous blood flow equals CVP.



The noninvasive technique for estimating CVP requires the subject to determine the intrathoracic pressure (measured at the mouth) which transiently stops jugular blood flow (measured by Doppler flowmeter). Congressman Bill Nelson demonstrated the feasibility of repeated CVP determinations daily throughout the STS 61-C flight.

Changes in CVP estimated noninvasively in one subject on STS 61-C are compared with those measured invasively in four subjects on Spacelab 1. The noninvasive estimate is also within the 95% confidence interval of the direct measurements.



Space Sciences and Applications

Solar System Exploration

Summary

Office of Space Sciences and Applications

Solar System Exploration

Summary

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Introduction

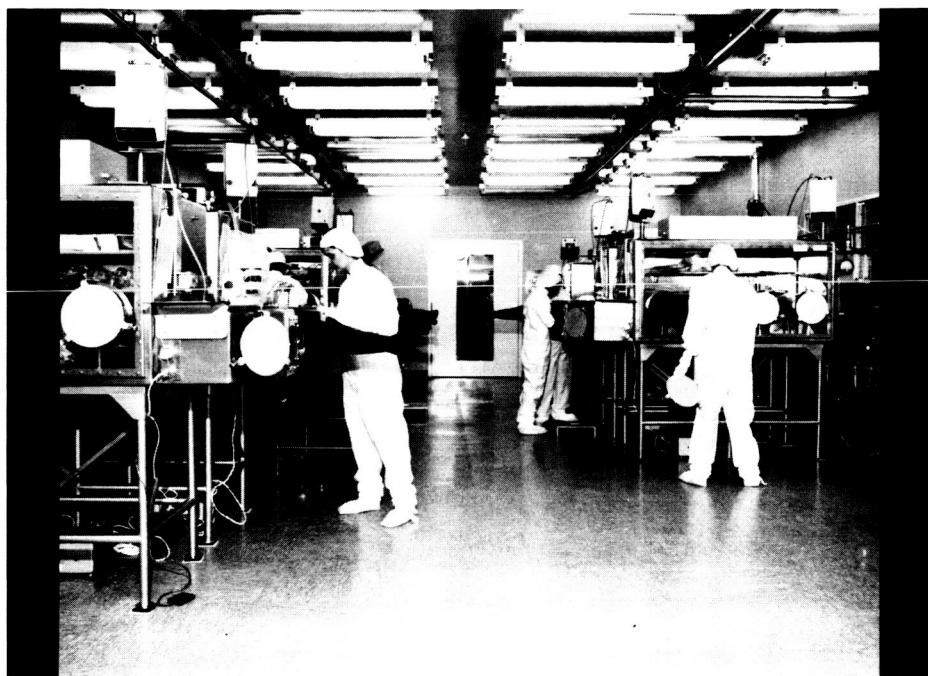
The exploration of the solar system as it is conducted at the Johnson Space Center (JSC) is primarily pursued through programs of planetary science research and space science research. Planetary science research is broadly aimed at understanding the processes that are significant contributors to the present and past stages of planetary history, principally to the terrestrial planets. These studies are performed by analysis of planetary materials, experimental simulation of planetary conditions and processes, remote-sensing observations, and theoretical modeling to interpret observational data. The research is basic to understanding requirements for future space missions, including science rationale and experiment design.

Space science research at JSC is broadly aimed at understanding the processes operating in the space environment and at applying that understanding to science and space flight operations in that environment. The research is most often basic research on the natural phenomena, either through direct study and measurement of the phenomena or through laboratory simulations. The research is basic to understanding requirements of current and future missions and to the design of scientific experiments.

Highlights of recent planetary science and space science research at JSC are described in the following summary.

Extraterrestrial Materials Studies

A fundamental part of JSC's solar system exploration effort is the study of extraterrestrial materials: lunar samples, meteorites, and cosmic dust. As scientists have found from insights made possible by the returned lunar samples, there is no substitute for the detailed study of actual samples of other worlds.



Lunar sample processing laboratory. Nitrogen-filled cabinets protect lunar samples from terrestrial contamination while research analysts study and prepare the samples for shipment to research laboratories. Lunar samples are stored in the vault that can be seen through the window at the end of the laboratory.

The Moon is the cornerstone of planetary science. Lunar sample studies have been fundamental in developing our understanding of the early evolution and continued development of planetary bodies and have led to major revisions in our understanding of processes for the accumulation of planetesimals and the formation of planets. Studies of lunar samples have increased our understanding of impact cratering, meteoroid and micrometeoroid fluxes, the interaction of planetary surfaces with radiations and particles, and even the history of the Sun. Furthermore, the treasures returned through the Apollo Program provide information that is required for a return to the Moon, beginning with new exploration (Lunar Geoscience Observer), followed by intensive study (new sample return missions), and eventually culminating

in a lunar base and in lunar resource utilization.

Much of the information gained from meteorites cannot be obtained from any other source currently available. The records preserved in these migratory chunks of matter that have come to Earth are difficult to read, but recent studies of them have revolutionized our understanding of the origin and early evolution of the solar system. Meteoritics, the study of meteorites, is an attempt to answer major questions about the age and origin of the solar system, the composition and evolution of the Sun and the planets, the presence of ancient magnetic fields and heating events, and the internal and surface processes on planets and asteroids. The scientific value of meteorites is vast in relation to their limited quantity, and the secrets contained in these

extraterrestrial gifts have only begun to be unraveled.

Cosmic dust, thought to be primitive solar system material, is another extraterrestrial material of intensive scientific study. The most common sources of cosmic dust are believed to be the small bodies of the solar system, asteroids and comets, although some of the dust may come from interstellar space. Both comets and asteroids are thought to be relatively unchanged objects left over when the larger planets formed, and dust from these objects should contain preserved clues about the origin of the solar system. Cometary dust is of particular interest and is the subject of studies by JSC scientists because comets must have formed in the outermost fringes of the original solar nebula where temperatures were low enough for ices to form and survive. In these distant regions, it is even possible that some of the interstellar dust particles that helped form the solar system were trapped and preserved in the icy comets.

Planetary Crustal Studies

The formation of planetary crusts through primordial differentiation is a fundamental topic of Earth and plane-

tary sciences. If meaningful models are to be developed for the evolution of the solar system, physical and chemical constraints must be developed for the processes involved in the evolution of the solid objects in the solar system. Crust-forming rocks, which represent material that was segregated from the mantles of the planets, can provide information about both crustal and mantle evolution.

Although the mantle of a planet can be expected to have evolved with time, present-day mantle compositions provide evidence about only the present result of that evolution. Many different evolutionary paths, however, may have been followed to the present point in time. Crustal rocks, which were formed at many different times during the evolution of a planet and which are essentially the only materials available for study, provide an excellent opportunity to trace the evolutionary path or paths.

In contrast to the Moon, where the predominant volume of the crust was formed in the first 10% of its history, the crustal rocks of the Earth represent 85% of the planet's history. This extensive crustal history of the Earth presents many complications in deciphering evolutionary

mechanisms that are not a problem on a planetary body such as the Moon, which has had little activity in the last 3 Gyr, but may also be viewed as an asset in identifying and elucidating the major mechanisms in the evolution of Earth's crust and mantle.

The isotopic signatures of source regions from which crust-forming rocks are derived are keys to understanding the evolution of the mantles and crusts of planetary bodies. At JSC, these signatures are the subject of research that will assist in developing hypotheses of terrestrial mantle-crust evolution and that will serve as a basis for interplanetary comparative studies.

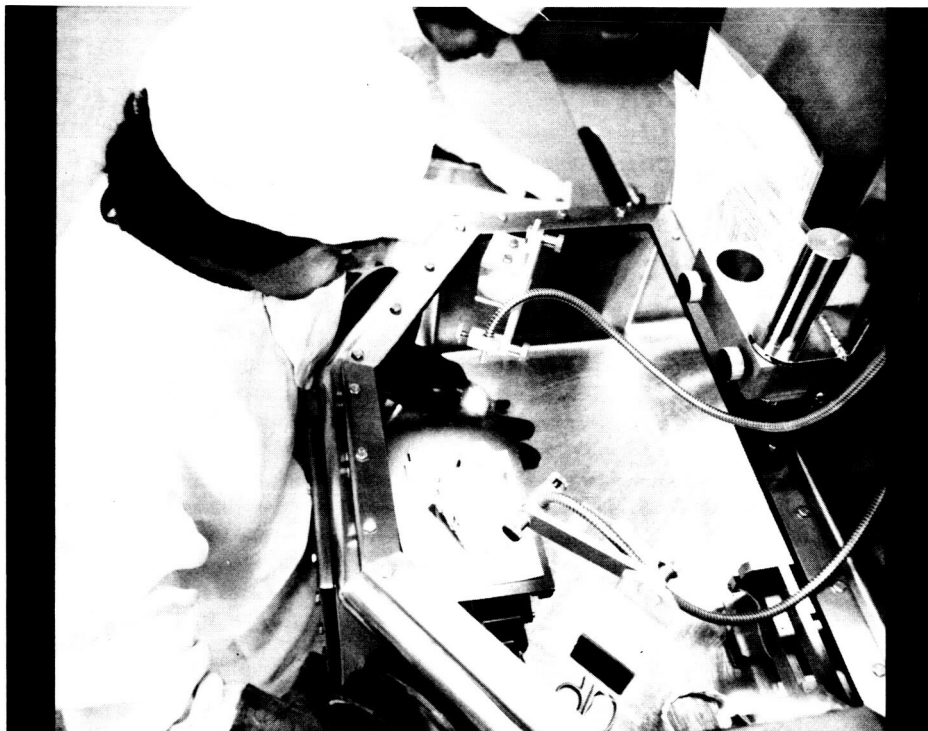
Mars Processes Studies

Even though the surface of Mars has been thoroughly mapped by Mariner and Viking orbiters, and rough chemical data from two sites have been obtained by the Viking landers, major unanswered questions about the planet still exist. The rocks look like volcanic lavas, but little is known about their chemistry and nothing at all about their mineral composition, ages, origin, and how they fit into the evolution of the planet. The reactions between the atmosphere and the rocks, and the chemistry of martian weathering, are also unknown.

Until such time as returned martian samples are available for study, scientists at JSC are attempting to understand better the chemical, physical, and mineralogical state of the martian surface and the weathering processes that modify it. Their research includes experimental and theoretical studies of the spectral and other physicochemical properties of pure and substituted iron-bearing compounds, theoretical and experimental studies of the effects of optical scattering on reflectance spectra, laboratory studies of materials weathered in terrestrial environments considered to be analogous to those on Mars, and studies of selected materials weathered in the laboratory under simulated martian conditions. This approach permits extensive feedback and scaling of processes observed under terrestrial conditions to martian conditions and permits study of processes not expected to be significant under terrestrial conditions.

Another JSC study of Mars processes has assessed the mineralogical factors associated with martian dust particles

Observation port of lunar sample processing cabinet. The horizontal window of the observation port permits detailed examination, microscopic study, and photography while the lunar samples remain in the protective nitrogen atmosphere of the processing cabinet.



as condensation nuclei and has linked those factors of significance to the formation of frosts on Mars. The experimental results not only confirm previous observations by atmospheric physicists that heterogeneous nucleation of ice depends significantly on the chemical and physical properties of the substrate but also indicate that, in general, crystalline minerals are expected to be better nucleators of condensates than are cryptocrystalline mineraloids. The significance of volatile materials on present-day Mars is of major scientific importance and has practical implications for planning future missions to Mars.

Earth Remote-Sensing Studies

The exploration of the solar system has many goals, but they can be reduced to a common denominator: fitting planet Earth into the ever-expanding informational mosaic of how the universe began, how it evolved, and how it is structured. A quarter century of Earth study from space has produced an immense volume of information, but it has also underlined the fact that a great deal is still to be learned about the near-Earth environment.

In 1965 and 1966, 2 of 17 scientific, engineering, and medical investigations conducted by astronauts during Gemini

missions involved synoptic terrain and weather photography experiments. The results of that and subsequent handheld photography by flightcrews clearly established the value of Earth photography for a multitude of scientific disciplines.

These investigations continue as JSC scientists provide support to Space Transportation System (STS) astronauts for the acquisition of Earth-looking photography. In consultation with scientific investigators, sites for photography are selected, researched, and documented in training manuals for each STS mission. Flightcrews are briefed on photographic techniques and on specific sites of geological, meteorological, and oceanographic interest. Support continues during missions in the form of uplinking ongoing environmental processes, and postmission activity includes debriefing flightcrews, cataloging and indexing mission photographs, and updating a computerized data base.

Because direct ground measurements of biomass and production for large areas of the Earth's surface are not feasible, JSC scientists also are attempting to demonstrate the validity of using remote-sensing techniques to monitor vegetation characteristics by measuring biomass, productivity, and

leaf area for specific regions of boreal forest. The overall goal of this research is to contribute to the measurement of the global biomass and net primary productivity. An understanding of physical relationships and appropriate statistical procedures are used to develop models relating biomass and productivity to leaf area indices, and relating leaf area indices to remotely sensed spectral images.

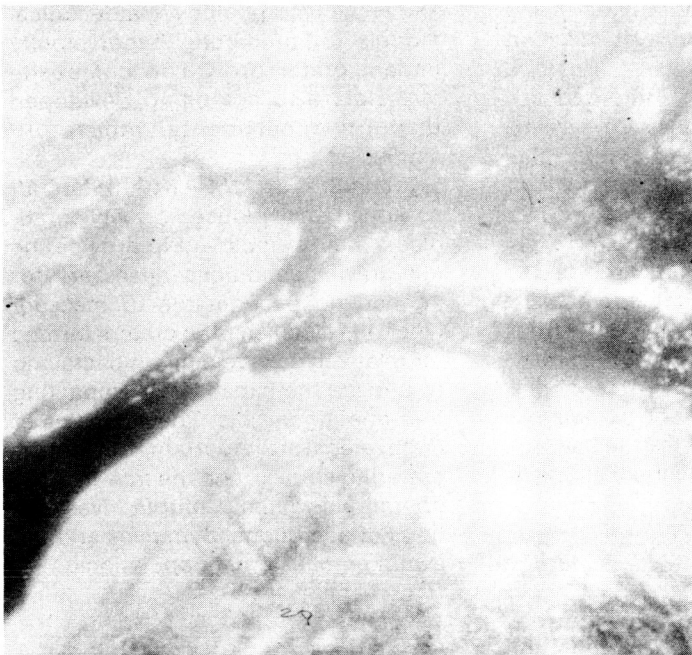
Still other Earth studies being conducted at JSC and employing remote-sensing techniques seek to determine whether there is unique information in the polarization of solar visible and near-infrared radiation reflected from the Earth's surface and atmosphere to support development of operational and/or advanced research sensors that include observation of that variable.

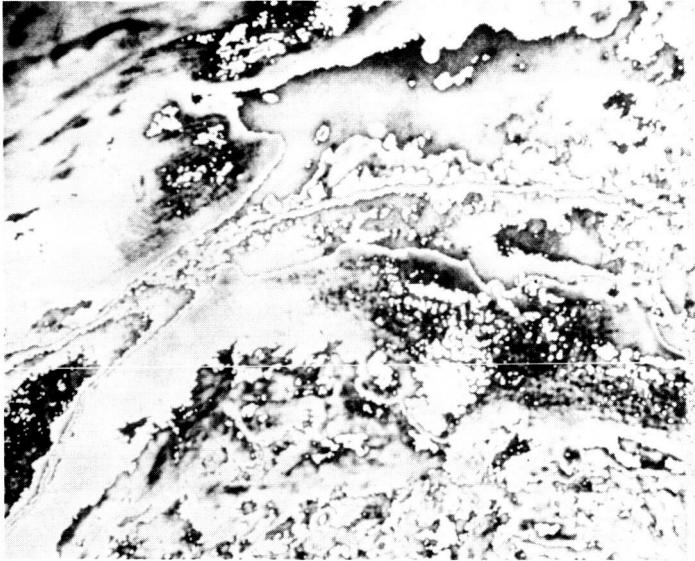
In a study sponsored by the Director's Discretionary Fund, some interesting results are being obtained. The following definitive statements can be made relative to the process.

1. The degree of polarization of terrestrial scenes as viewed from orbital altitude, normally between 0 and 0.2, can be 0.5 or more.

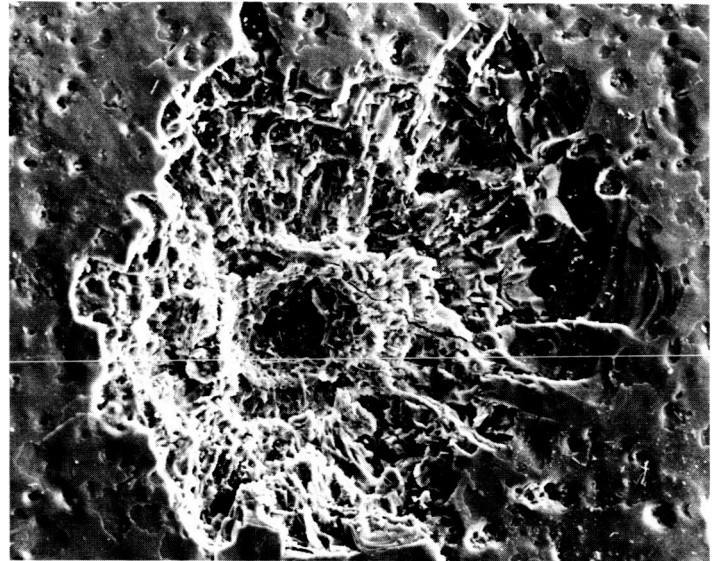
2. Degree of polarization appears to be suitable as an additional variable for classification of some scene components.

Polarization pair of images of the Red Sea and the Gulf of Aden taken during STS mission 51-A. (Image reversed for analysis purposes.) Maximum image to the left includes polarized reflected light plus one-half of the unpolarized light. The image to the right contains the other one-half of the unpolarized light.





Contours in degree of polarization. Tight gradients in the water along the Red Sea indicate turbidity or bottom contours. Note fine detail in land patterns.



Impact pit in thermal protection system tile of Space Shuttle *Atlantis* after maiden voyage. This impact was made by orbital debris.

3. Systematic changes in degree of polarization can occur across a scene because of geometric effects. Reversal in phase of polarization occurs within a scene at times.

4. There is a distinct improvement in signal-to-noise ratio when the polarized component is discarded in many scenes as the atmospheric scattering contribution to path radiance is diminished. A similar effect is indicated for water penetration.

5. Some patterns not discernible in intensity are apparent in degree of polarization images.

6. Significant variation in degree of polarization occurs between colors in some scene components.

Radiation Environment Studies

The work of JSC scientists also involves directly supporting operational radiation dosimetry requirements for all STS missions, providing the conceptual design and development of advanced radiation dosimetry systems for the Space Station, serving as co-investigators of complex radiation experiments both on the STS and on the Space Station, and conducting radiation environment studies.

A recent special meeting held under the auspices of the Space Station Radiation Committee at NASA Headquarters resulted in reviewing the use of radiation belt models to predict radiation doses expected in the Space

Station. Among other findings, it was determined that the models date back to 1964 and 1970 and, in order to update the models, new data are required. Such an update is very important in view of the significant temporal decrease in the strength of the Earth's magnetic dipole moment and the associated adiabatic effects on the spatial distribution of the trapped radiation. Experimental and analytical investigations in this area are being pursued by JSC scientists, who also are using dosimetry data obtained on projects ranging from Project Mercury to the Space Shuttle Program to draw conclusions about the stability of the Earth's inner Van Allen belt radiation environment.

A unique technique to extract trapped-radiation belt spectra using passive dosimeters carried aboard STS vehicles is another recent accomplishment of JSC scientists. Data from Space Shuttle missions STS 51-D, STS 51-G, STS 51-F, and STS 51-B have been analyzed to show that the measured spectra are harder than the predicted spectra from the "best" trapped environment model, the modified Sawyer-Vette AP-8 model. This result is important because it provides hard evidence that the Sawyer-Vette AP-8 model is incorrect at Space Shuttle orbital altitudes.

Impact Studies

Previous studies have indicated that orbital debris may be a significant

problem for future space activities. In this area, the primary objective of experimentation now being performed at JSC is to understand better the impact processes and the collisional hazards posed by meteoroids and orbital debris for spacecraft and materials used for space applications. Impact features in spacecraft and exposed surfaces of satellites are being analyzed to determine the relative proportions of micrometeorites and orbital debris particles and to determine the particle types and compositions for each major particle class based on impact residue and impact morphology. Mathematical models for predicting hypervelocity impact crater growth in composite materials also are being developed through experimental laboratory studies.

In addition, the NASA KC-135 aircraft equipped to fly reduced-gravity parabolas is being employed to provide the low-gravity conditions necessary for conducting experiments to measure ejection velocities from craters formed by relatively low-velocity impacts and to provide the capability of impacting free-floating targets. The velocities of crater ejecta are important in planetary cratering studies, and the free-floating operations will be useful in investigations of accretional dynamics and the evolution of asteroid populations.

Space Sciences and Applications

Solar System Exploration

Significant Tasks

Lunar Zircons

PI: Charles Meyer, Jr./SN2
Reference OSSA 11

One of the outstanding problems of lunar science is to determine how and when the lunar crust formed. One model is that a global magma ocean slowly crystallized to form the wide diversity of rocks that were found in the lunar highlands. Lunar granite would be the last rock to form in this sequence of differentiation. According to this model, the date when the initially molten lunar crust finished crystallizing can be determined from dating the granite.

Zircons are important in the geochronological study of lunar samples. Although zircons are rare and difficult to find in lunar samples, there are a few in the trace-element-rich breccias from the lunar highlands. Usually, they are found as individual crystals unattached to other minerals. A few have been found included in small rock clasts in the matrices of the breccias.

The uranium (U) content of lunar zircons ranges from 10 to 500 p/m. The radioactive decay of uranium to two isotopes of lead (Pb) provides a way to measure the age of the zircons and of the rock fragments in which they are found. The uranium and lead isotope ratios in small zircons found in thin sections of lunar samples are measured in situ using a sensitive high-mass-resolution ion microprobe at the Australian National University. The illustration summarizes the ages obtained in this investigation. These results show that zircon-containing lunar rocks are older than the majority of lunar rocks.

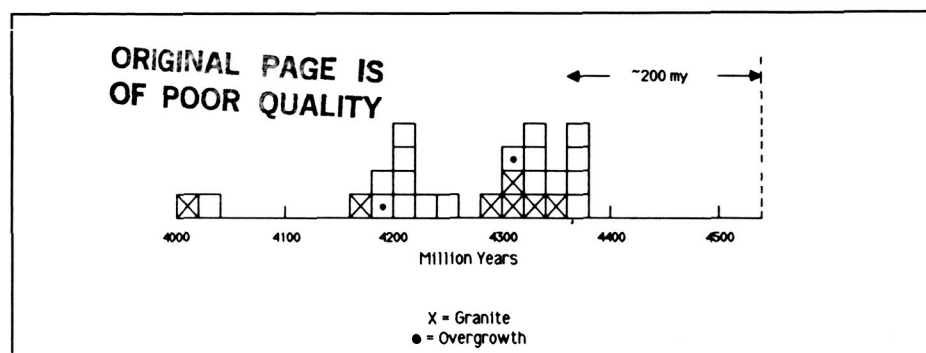
Tiny euhedral zircons located in small fragments of lunar granite are found to have the highest uranium content and can easily be dated by the ion microprobe technique. The ages of several granites are determined to be greater than 4300 Myr, which would mean that the original lunar magma ocean finished crystallizing within 200 Myr of the initial formation of the Moon.

In general, lunar zircons are relatively homogeneous in both chemical and isotopic composition. However, the zircon in a unique clast found in a thin section of lunar breccia 73235 has been found to be unusually variable in com-

position. This clast consists of numerous fragments of broken zircon included in a calcium-rich plagioclase assemblage with a polygonal metamorphic texture. Variations in backscatter-electron intensity of the zircon clearly define chemically distinct regions within the interior as well as a unique overgrowth. (See figure.) These regions are found to be chemically distinct in trace amounts of uranium, yttrium (Y), and ytterbium (Yb). The overgrowth has distinctly different Th/U and Y/Yb ratios. Isotopic analysis of the interior and of the overgrowth allow us to piece together the following story. Approximately 4310 Myr ago, a relatively large (>500 μm), zoned zircon crystallized

within a plagioclase-rich rock. Some time afterward, this zircon-plagioclase assemblage was fractured and recrystallized. An overgrowth of new zircon occurred 4180 Myr ago. Based on the polygonal texture of the plagioclase, this was a metamorphic event. Finally, this clast was incorporated in a melt sheet derived from a large impact about 400 Myr ago.

Until recently, it has not been possible to study the early history of the Moon because large unbrecciated samples were required for geochronological studies. The lunar soil samples, core tubes, and breccias contain many small rock fragments that can now be studied by this new microscopic technique.



Summary of ion microprobe ages ($^{207}\text{Pb}/^{206}\text{Pb}$ ages) of lunar zircons.

Backscatter-electron image of zircons in lunar sample 73235 showing variations in chemical composition and overgrowth.



Composition of Comet Halley Dust Particles

PI: Herbert A. Zook/SN3
Reference OSSA 12

Comets are remarkable objects. It is commonly believed that all of the several hundred comets observed to date originated with the formation of our solar system about 4.6 Gyr ago and have been in orbit around our Sun ever since. No comet has ever been observed to arrive directly from interstellar space. The comets that we actually observe, however, are all rather recent visitors to the inner solar system. The dramatic tail or halo that alerts us to the presence of a comet also is evidence that the comet is rather rapidly disintegrating with time. Comets probably do not remain active for more than a few thousand years in the terrestrial region of the solar system. Comets, therefore, appear to have been stored in the cool outer reaches of our solar system for all but the last tiny fraction of their lives. They may have retained, in unaltered form, the original gas and dust grains from which they originally accreted. These grains may, additionally, be primordial grains from the nebular cloud which collapsed to form our solar system. Comets are the most promising storage place for such grains, if they exist in our solar system.

Until the Giotto spacecraft flyby of Comet Halley on March 14, 1986, and the flyby of the two U.S.S.R. Vega spacecraft the previous week, however, almost nothing was known about the chemical composition of cometary grains. All three spacecraft had nearly identical experiments onboard to measure the chemistries of individual cometary dust grains, and all three experiments gave excellent results.

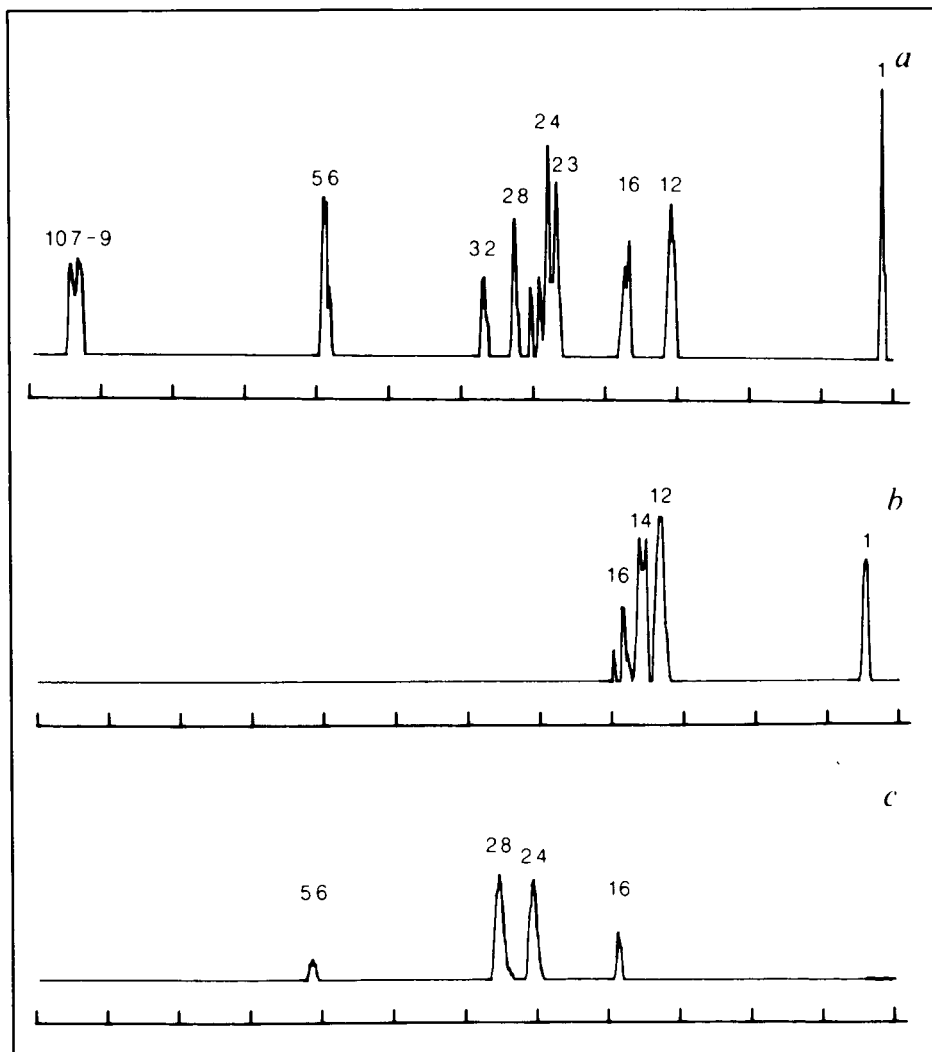
In the figure are shown three examples of mass spectra obtained on Halley dust particles. The peaks labeled 12 and 16 are due to singly ionized carbon and oxygen ions, respectively. One clearly sees, in spectrum a, the three isotopes of magnesium — 24, 25, and 26 (the last two are not labeled) and the two isotopes of silver — 107 and 109. The latter ions are derived from the 10%-silver-doped platinum target. One also sees sodium, silicon, sulfur, and iron in this spectrum. In spectrum b, only low-Z elements are seen, a not uncommon occurrence. Spectrum c

depicts an impact by a pure silicate grain, apparently a magnesium-rich olivine or pyroxene. Other nearly pure mineral grains, such as sodium chloride and iron sulfide, were also observed.

Although analysis of the Comet Halley dust grains and gas in the coma is only in the preliminary stage, much has already been learned. The gas-to-dust ratio appears to lie somewhere between 4 and 10, the gas is mostly water (80% to 95% H_2O) with lesser amounts of carbon dioxide and other gases, and the dust grains are highly variable in composition. This last observation is

very interesting as it was not known before flight whether the dust grains would vary in composition from grain to grain. Enigmas remain. Are the dust grains in their primordial state — which would indicate a variety of source regions — or have they been chemically processed in the comet to give the variety of chemistries that we observed? How is the gas stored? Is it as crystals of ice between the dust grains or does it reside in the pore space of fragile, porous dust grains? More work lies ahead to resolve these and other questions.

Three separate mass spectra obtained with the PIA time-of-flight mass spectrometer during the Comet Halley flyby on March 14, 1986. The vertical scale is logarithmic, and time increases from right to left. Most peaks are labeled with the associated mass numbers. The figure is taken from Kissel et al., *Nature*, vol. 321, 1986, pp. 336-337.



Evolution of the Archean Mantle

PI: Donald A. Morrison/SN4
Reference OSSA 13

The terrestrial planets are separated into core, mantle, and crustal domains. The compositions of these domains and the chronologies of their development are crucial elements in planetary evolution. The mantle of a planet evolves with time, and many different evolutionary paths are possible. Crustal rocks formed by partial melting events in the mantle at different times provide some indication of the evolutionary path followed.

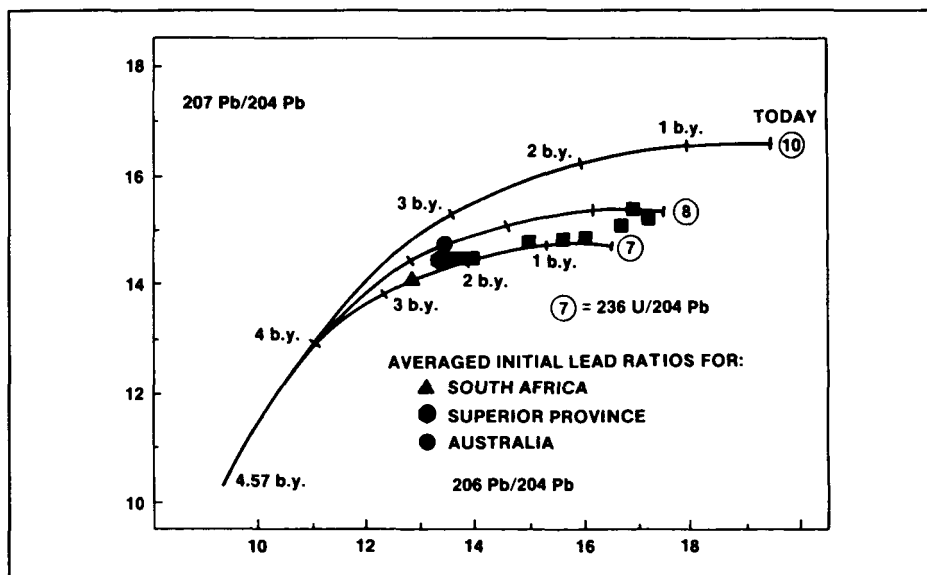
Significant understanding of the basic processes involved in the generation of the Earth and Moon crust and mantle has been achieved through consideration of the uranium-lead (U-Pb) system. The Pb isotopic system is very sensitive to differences in U/Pb ratios established early in Earth mantle evolution because of the relatively short half life of ^{235}U and the consequent early and rapid production of ^{207}Pb . Existing data, although far from complete, suggest that major continental blocks of the Earth were derived from mantle sources which followed different evolutionary paths. The Superior Province of Canada, for example, appears to have been derived from a mantle source with a lower U/Pb ratio than those of other regions.

To test this hypothesis, scientists have completed Pb isotopic analyses for two 2.7-Gyr intrusives in the Wabigoon subprovince of the Superior Province. The initial lead isotopic compositions are among the lowest measured for 2.7-Gyr rocks of the Superior Province. The ratios imply a single-stage U/Pb ratio of 7.5, significantly less radiogenic than the mantle value predicted by the classic plumbotectonic model. The low U/Pb value indicated is in agreement with the low values for radiogenic strontium (Sr) and neodymium (Nd) obtained for the same units. Collectively, the data suggest that the mantle source, or sources, of the western Superior Province crustal rocks has a unique signature and that it is more depleted in radiogenic parent isotopes than is the mantle underlying most other continental terrains.

A comparison between major continental blocks is shown in the figure. The squares represent new Superior Province data. The lead data show that the source region of the Superior Province had been depleted at least several hundred million years prior to the onset of the pervasive 2.7-Gyr magmatism. The depletion may be primary or the result of earlier melting events.

The lead data also show that preexisting crust (more than 50 Myr older approximately) was not involved in the generation of the rocks analyzed. Older crust (>3.0 Gyr) does occur in the western Superior Province, and its lack of involvement in later crust formation, either through recycling or partial melting, has important implications for the mechanism of crust-mantle interaction during the Earth's Archean period.

Averaged initial lead ratios for South Africa, Superior Province, and Australia.



Spectral Evidence for Hematite on Mars

PI: Richard V. Morris/SN4
Reference OSSA 14

The inverse problem in the interpretation of laboratory reflectance spectra of well-characterized materials is to use the data to infer the physicochemical state of remotely sensed planetary surfaces. It is difficult to establish uniqueness in such inversions because planetary surfaces are complex assemblages of phases and because the factors that influence reflectance spectra are not well enough understood. The reflectance spectra of Mars, obtained mainly by Earth-based telescopic observations, are specific examples of the inverse problem.

As shown in the first figure, the composite bright region spectrum of Mars is characterized by features that include an absorption edge (400 to 750 nm) through the visible wavelength region that is responsible for the characteristic reddish color of Mars and a shallow absorption band centered near 870 nm. Both of these spectral features are generally attributed to ferric iron. In addition, the relatively featureless nature of the absorption edge and the shallow nature of the band have suggested to some investigators that the ferric-containing phases are poorly crystalline, implying that specific mineralogical identifications are not possible. The 870-nm band minimum does imply that the ferric oxide is hematite (Fe_2O_3). However, the absorption edge for hematite, as represented by crystalline powders having mean particle diameters larger than approximately 100 nm, is excessively steep (560 to 750 nm) to be consistent with the martian data. The problem with this line of reasoning is that it presumes that the aforementioned hematite spectra are in fact representative for hematite over all particle diameters.

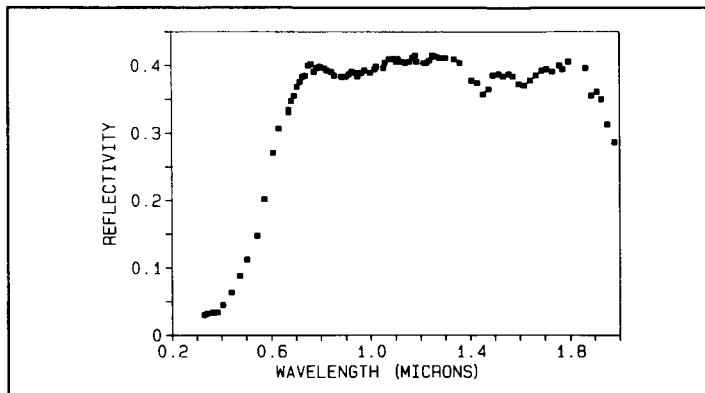
During the past year, scientists at the Johnson Space Center have studied the spectral properties of extremely fine-grained (less than approximately 50 nm) hematite particles and found that their spectral properties differ markedly from those of their coarse-grained equivalents. The hematite particles were produced by impregnating silica gel that has 6-nm-diameter pores

with a ferric nitrate solution and then heating the impregnated gel at 550° C. Representative spectra for samples containing 0 to 24 wt% Fe_2O_3 are illustrated. Except for the absorptions near 1400 and 1900 nm that are inherent to the silica gel and not due to ferric iron, the trend is for the absorption edge to move into the visible region and for the absorption at 870 nm to deepen and change in shape from inflection, to plateau, to minimum. The spectrum of the most iron-rich sample is essentially the same as that typically found for pure and relatively coarse hematite powders. Presumably, the inflection and plateau result because the hematite particles in those samples are so small that they do not have a fully

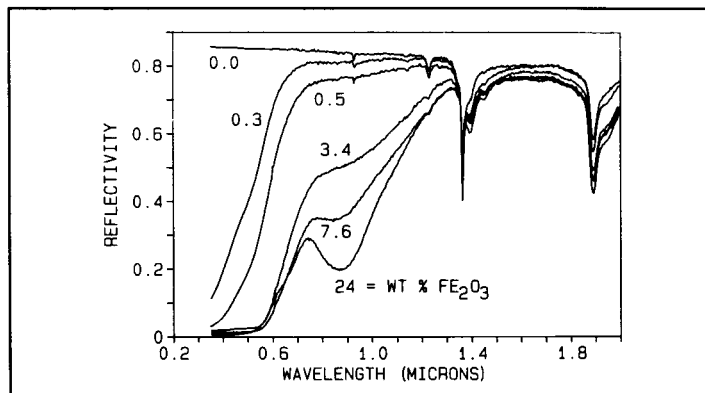
developed and ordered hematite structure over most of their volumes.

The martian spectral features caused by ferric iron can now be accounted for solely, but perhaps not uniquely, by hematite present in a range of particle diameters. This conclusion can be seen in the third figure, which is the spectrum of a mechanical mixture containing 5% of the silica gel with 24 wt% Fe_2O_3 and the balance containing the gel with 0.5 wt% Fe_2O_3 . Like the martian spectra, this spectrum has a shallow band minimum at 870 nm together with an absorption edge extending from 400 to 750 nm. Thus, the identification of the phase hematite as a mineral on the martian surface is entirely consistent with the spectral data.

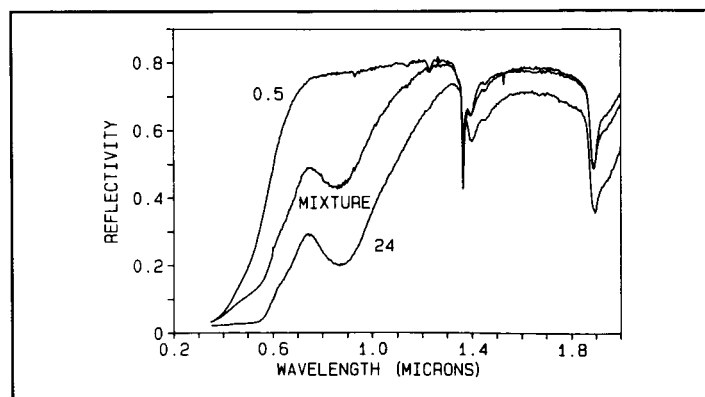
Mars bright region spectrum.



Representative spectra for various hematite concentrations.



Spectrum of mechanical mixture of silica gel with hematite.



Monitoring the Earth With Space Shuttle Photographs

PI: Charles A. Wood/SN4
Reference OSSA 15

From space, the Earth is seen to be an integrated body, a continuous mosaic of land, water, and clouds that blend without the artificial boundaries that appear on most maps. To understand and to utilize the Earth wisely, we must consider it as an entity. Volcanic eruptions anywhere on the globe need to be monitored to assess the climatic and geodynamic potential on a continental scale. Deforestation in the Amazon River basin or along the Congo River affects chemical inputs into the atmosphere and the biological diversity of the largest remaining natural component of the biosphere on Earth. Likewise, geologic structures that control earthquakes or mineral distribution do not stop at national boundaries. Global monitoring of the Earth is at hand.

Fortunately, a remarkable photographic documentation of the state of the Earth has been accumulating during the last 25 yr. This long record has accrued through astronaut photography of the Earth. These photographs differ from satellite images in that each of the nearly 70 000 pictures was taken because a scientifically trained astronaut recognized a feature of interest on land, in the oceans, or in the atmosphere. The pictures taken during the first 24 Space Shuttle missions are especially valuable for studying the global systems of the Earth because they are now completely cataloged and thus can be more easily acquired and used than could previous Earth photography. The cataloging of the 37 000 Space Shuttle photographs, as well as geoscientific training of the Space Shuttle astronauts, was coordinated by the Johnson Space Center (JSC). Currently, JSC scientists are developing automated techniques to improve efficiency in selecting targets for future photography by Space Shuttle astronauts. Additionally, information on Earth photographs taken by Gemini, Apollo, and Skylab astronauts is being entered into the computerized data base to allow these early pictures to be retrieved easily for crew training and scientific analysis.

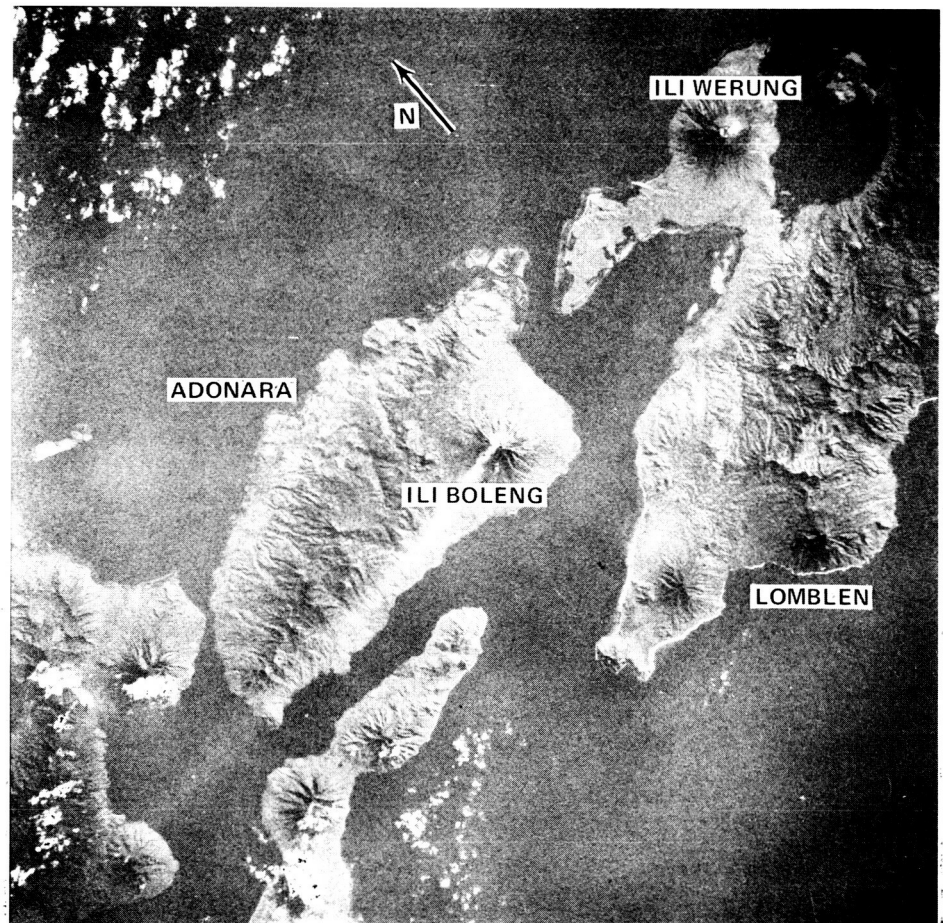
Photographs of the Earth from space provide scientists with broad synoptic views that encourage the investigation of interrelationships rather than of details. A single Space Shuttle photograph can depict the geology of a mountain range or a fault belt in its entirety, rather than in the piecemeal fashion required for aerial photographs.

Photographs taken by astronauts also document new discoveries of features that the human observer realizes are important. Thus, photographs by Gemini astronauts demonstrated the existence of large-scale circulatory eddies in the oceans that were hard to recognize from the limited perspective of shipboard data. Additionally, astronaut photographs reveal details of hurricanes

and other weather phenomena that are invisible to weather satellites, but excessively large or inaccessible for study from the ground or from airplanes.

JSC is working with other government organizations to make this national legacy of space photographs more easily available to researchers. The Earth Resources Observation Systems Data Center in Sioux Falls, South Dakota, uses a computerized version of catalogs of Space Shuttle pictures to inform customers of the Earth regions that have been photographed. The Air and Space Museum of the Smithsonian Institution is currently completing a single videodisk of all 37 000 Space Shuttle photographs to be sold to the public at a nominal price.

Space Shuttle astronauts take advantage of an orbital vantage point to detect and document unexpected events such as this volcanic eruption in Indonesia. Crewmembers of the STS-8 Space Shuttle mission photographed an eruption plume from Ili Boleng volcano on the island of Adonara (40 km long by 20 km wide), but the eruption was not otherwise recorded.



Satellite-Derived Leaf Area Index and Vegetation Maps as Input to Global Carbon Cycle Models

PI: Gautam Badhwar/SN3
Reference OSSA 16

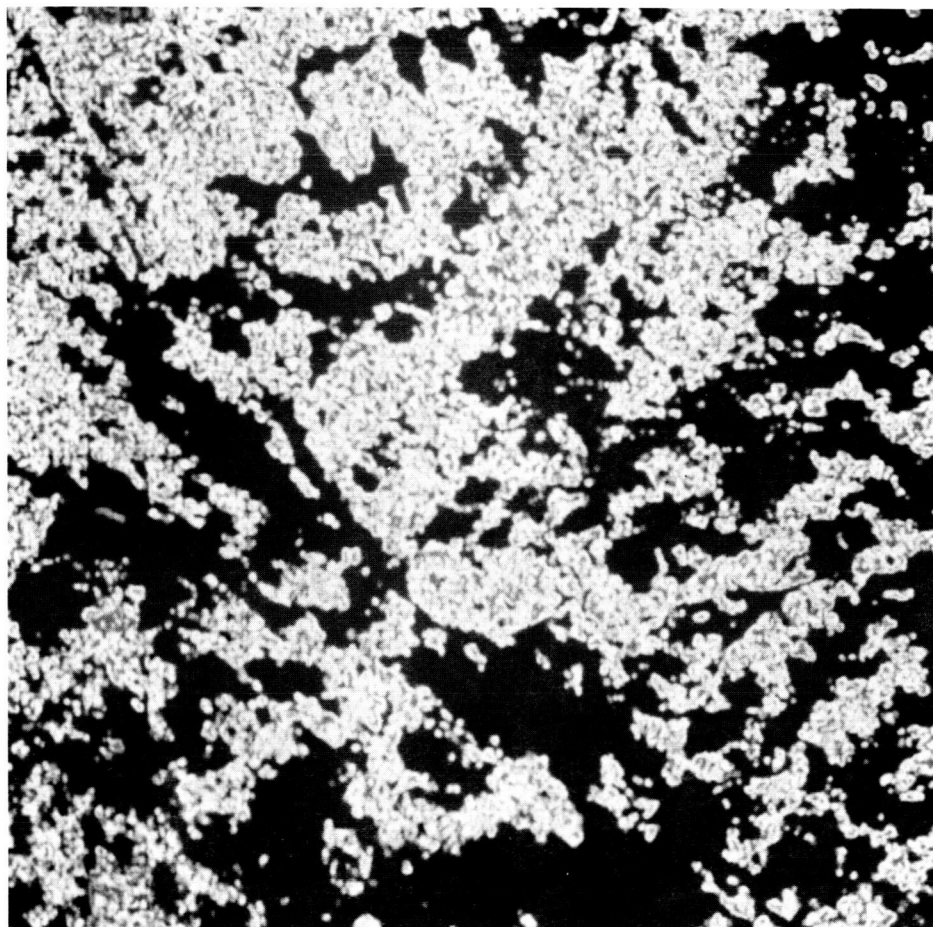
The role of natural and anthropogenically altered land surface features in physical, chemical, and biological processes on a global scale is of concern to an expanding world population and is exemplified by the carbon dioxide climate controversy. The reason for this concern lies in the very complex feedback processes at work in the Earth land/atmosphere/ocean system. This controversy has underscored the need for improved understanding of the atmosphere, of oceans, of biota, and of their interactions. The critical function of terrestrial vegetation as a transport medium for the flux of important constituents, such as carbon, has been well recognized and can be seen in the annual cycles of the atmospheric carbon dioxide measurements. These observations clearly indicate that vegetation actively participates in the storage and cycling of carbon and interacts directly with the atmosphere. The current estimates of the total land area, the biomass, and the productivity of vegetation are known to only a factor of 2 at continental scale, and to a factor of as much as 10 at plot level. Satellite-carried sensors provide an objective and practical method of vegetation mapping.

In 1983 and 1984, a combined helicopter/aircraft/satellite-based experiment was performed in the Superior National Forest to map types of vegetation and to determine the leaf area index of forest canopies. This hierarchical approach is unique in that it provided, for the first time, a calibrated means of going from plot level to a continental scale and knowing the information loss that occurs on the way.

Analyses of both the helicopter and the aircraft data have shown that the spectral data can allow a determination of the leaf area index to $\pm 20\%$ at plot level. With this calibration, the leaf area index maps over the region from Landsat multispectral scanner data in 1979 and 1982 show definite changes in vegetation and the leaf area of various canopies. (See figure.) These results suggest that satellites can provide key input to global carbon cycle models. These studies are critical if capabilities to monitor the vegetative resources of the Earth and to understand the life-sustaining processes of the Earth are to be developed.

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Percentage change in the leaf area index from 1979 to 1982 for aspen canopies near Ely, Minnesota.



Radiation Environment Models and the Atmospheric Cutoff

PI: Andrei Konradi/SN3

Alva C. Hardy/SN3

Reference OSSA 17

To predict the Space Station radiation environment expected after the turn of the century, scientists at the Johnson Space Center (JSC) used the radiation environment models AP-8 MIN and AP-8 MAX for protons with energies above 30 MeV and used the magnetic field model IGRF 1975. In the process, scientists encountered an almost exponential increase of the radiation intensity with time in the South Atlantic Anomaly (SAA) region. Such an unexpected and rather unrealistic result forced a review of the calculation methodology and the structuring of the models.

The figure shows flux-altitude profiles for the years 1965, 1995, and 2025. These profiles were calculated at an altitude of 500 km at the center of the trapped-radiation SAA. Not only does the flux apparently increase with time, it also increases disproportionately at low altitudes and even below the surface of the Earth. If real, such an increase would have significant implications.

Interpretation of this phenomenon rests simply on the fact that the particle flux contained in the model as a function of magnetic field intensity B and beam path length L has built into it, also as a function of B and L , the atmospheric cutoff of 1964 for solar minimum and 1970 for solar maximum. In other words, within experimental uncertainties, AP-8 MIN and AP-8 MAX represent for those two epochs the average particle distribution as it existed deep within the magnetosphere and within the atmospheric cutoff region.

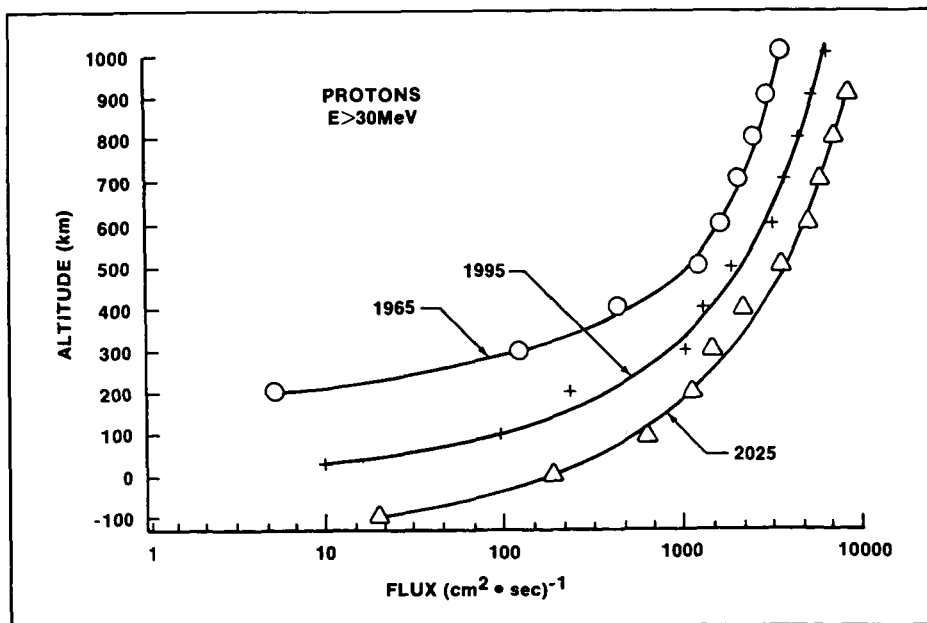
As a result of the well-documented temporal decrease in the magnitude of the geomagnetic dipole moment, locations of a fixed magnetic field intensity are found at progressively closer distances to the Earth. Consequently, flux values associated with fixed B values move to lower altitudes, and the models artificially move the atmospheric cutoff to lower altitudes. Since the flux gradient within the geomagnetic cutoff is very steep, the order of magnitude of the flux increases within a short time period, and even subterranean fluxes are predicted. Obviously, this flux is an artifact of the model and has no physical significance.

Pending the development of more sophisticated models that take into account the independence of the atmospheric cutoff from the magnetic field, the scientists at JSC recommend two approaches that will produce reasonable results.

1. AP-8 and AP-8 MIN and MAX models should be used in conjunction with appropriate magnetic field models for epochs 1964 and 1970, respectively, and no attempt should be made to project the radiation environment into the future. Although this approach will produce reasonable predictions of exposure doses when averaged over all longitudes, it may give poor results for individual orbits because the westward drift of the magnetic field is not accounted for.

2. An alternate and operationally more accurate approach was suggested by Vette and Sawyer. This approach involves expressing the particle flux not as a function of B and L but rather as a function of B/B_0 and L , where B_0 is the minimum value of the magnetic field on an L shell. Both L and B/B_0 are nearly independent of the value of the magnetic dipole; thus, a particle distribution tied to these parameters will show little change with time. The trapped-radiation environment models currently available from the National Space Science Data Center incorporate these changes.

Projections of South Atlantic Anomaly flux as a function of altitude as determined using magnetic field model IGRF 1975.



Solar Maximum Mission Satellite and Space Shuttle Orbiter Impact Craters

PI: David S. McKay/SN4
Reference OSSA 18

The size distribution, flux, composition, and source of orbital debris in the size range of about 1 mm and smaller is not well understood, although preliminary data indicate that such material may be an important component of the entire orbital debris complex. Submillimeter debris may have significant effect on critical spacecraft components including lenses, windows, mirrors, sensors, critical electronics, and other hardware which must be directly exposed to the space environment. To identify material in this size range using optical and radar detection is difficult. However, a significant amount of this material is known to have impacted spacecraft surfaces, and some of these surfaces have been analyzed. Essentially, all returned spacecraft hardware which has had any significant exposure to space contains small impacts from orbital debris as well as from tiny micrometeorites.

In most cases, the shape and morphology of the impact feature provides some information on the velocity of the projectile. Significantly, most impact features contain some residue from the impacting projectile, and it can be analyzed using sophisticated electron microscope techniques.

Detailed analyses of impacts on these returned surfaces should provide hard data on the composition, the flux, the velocity distribution, and, ultimately, the source of submillimeter orbital debris. An additional important implication of analyzing the submillimeter debris population is that this population will provide a flux curve that can be extrapolated to larger sizes and compared to optical and radar data. This comparison will provide independent information on the entire orbital debris complex.

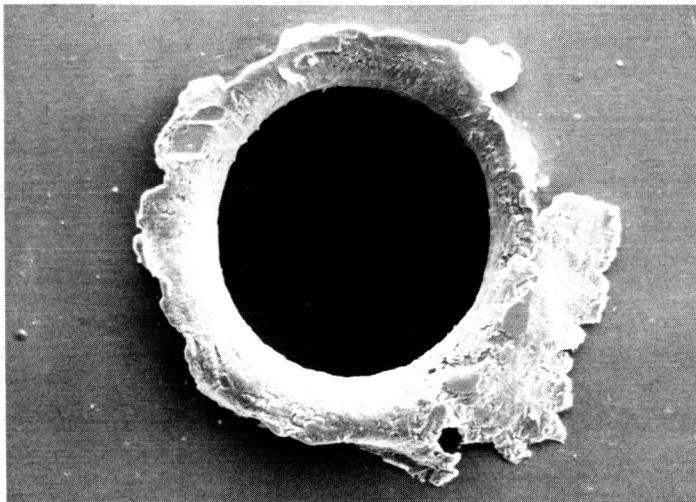
Scientists at the Johnson Space Center (JSC) have analyzed more than 1 m² of returned thermal blanket from the Solar Maximum Mission (Solax Max) satellite, which had spent more than 4 yr in space before retrieval. Returned thermal insulation blanket material (Kapton and Mylar) and louvers (aluminum) contain more than 1000 impact holes and craters larger than 40 μ m in an area of approximately 1 m². The largest hole is about 1 mm. The JSC scientists have cataloged these features and made them available to interested investigators throughout the country for scientific study. Approximately one-third of these impacts were made by micrometeorites, but at least one-third and possibly two-thirds were made by orbital debris in the submillimeter size range. A significant component of the impacting projectiles appears to be composed of paint

pigments, apparently released into orbit from degraded spacecraft paints. Other materials include aluminum-rich residues derived from solid-propellant rocket exhausts, from spacecraft fragmentation, or from both sources and a variety of materials including substances of low atomic number (possibly plastics) which have not yet been associated with specific spacecraft components.

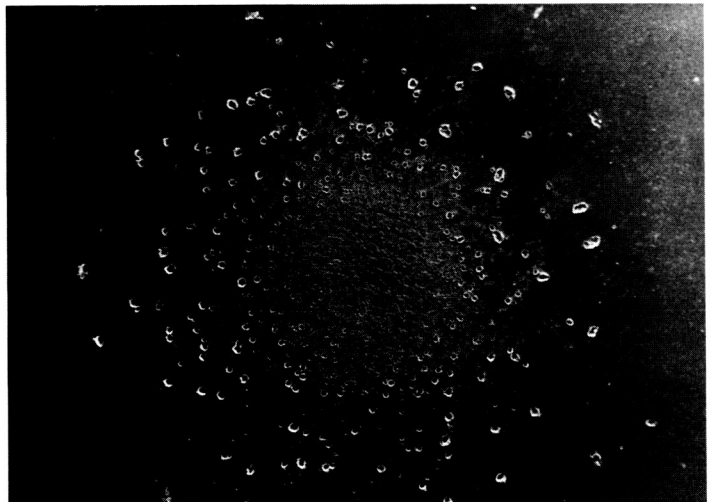
In a related study of Space Shuttle tiles from the Orbiter *Atlantis* immediately after her maiden voyage, researchers found one high-velocity impact crater likely formed by orbital debris. This crater, which was clearly caused by a hypervelocity impact, created a melted pit and formed a surrounding spall zone. Analysis of residue in the pit area revealed traces of aluminum, iron, and chromium. Because aluminum and chromium are not abundant elements in most micrometeorites, the researchers believe that the projectile was most likely an orbital particle. This impact did not do any significant damage because the crater (spall) diameter was less than 1 mm, but it does suggest the possibility of damage to future Orbiter flights and to the Space Station from larger objects or from the growing orbital debris complex.

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Impact hole in a Solar Max satellite aluminum louver returned from space (scanning electron microscope (SEM) photograph).



Spray pattern on an aluminum panel immediately beneath the Solar Max satellite impact hole shown in previous photograph. This spray pattern contains melted and splashed aluminum from the outer aluminum layer as well as residue from the projectile. Note the change in scale of the photograph. This spray pattern is about 4 times larger than the overlying hole (SEM photograph).



Impact Experiments in Reduced-Gravity Environments

PI: Mark J. Cintala/SN12

Friedrich Horz/SN4

Reference OSSA 19

Impact cratering occurs on every solid object in the solar system; no other geologic process has operated as continuously or as inexorably. In efforts to unravel the physics behind the process, planetary scientists have determined that the gravitational acceleration is a principal factor in determining the sizes and possibly the shapes of craters. Theoretical investigations predict that, under otherwise constant impact conditions, a crater would be larger if the strength of the gravity field in which it formed were decreased. At the same time, the duration of crater growth would increase. It is important to understand the relationship between crater dimensions and the g-level, for example, if one were to compare impact craters on different planets. Another important factor influenced by gravity is the time required for a given crater to grow; this time is directly related to ejection velocities. The removal of potential meteorites from their parent bodies is intimately tied to this gravity-scaling effect.

Most solid objects in the solar system have gravitational accelerations substantially lower than that of Earth. Thus, determining the effects of gravity on various aspects of the cratering process would require experimentation in different gravity fields. Some aspects can be and have been examined at high g-levels through the use of centrifuges; study of other phenomena, however, require low g-levels. The Space Shuttle Orbiters and the Space Station could, in principle, serve as platforms on which low-gravity experimentation could be conducted. With the potential use of these vehicles in mind, researchers are conducting a series of investigations to provide engineering and scientific data for use in designing the facilities to be flown and the experimental program that might be pursued.

The NASA KC-135 aircraft equipped to fly reduced-gravity parabolas can support low-g accelerations for more than 45 sec at a time, depending on the desired g-level. It also can support instruments sufficiently large that useful impact experiments can be performed

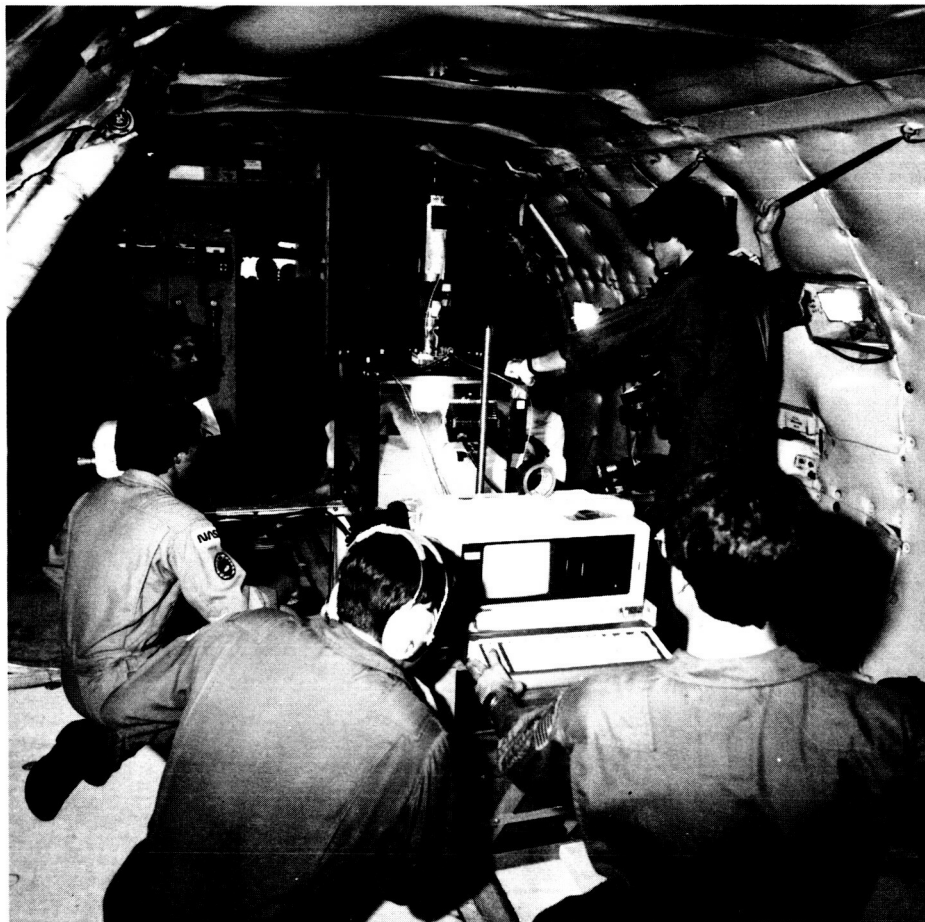
during flight. An impact facility for flight on the KC-135 has been constructed. It consists of an impact chamber, cameras, lighting, a modified air-driven pellet gun, and a microcomputer for sequencing and collecting acceleration and cabin pressure data. Some preliminary experimentation has been conducted during parabolic flight, resulting in 27 shots to date at g-levels ranging from 0.08g to 0.53g.

These experiments were only of a precursor nature and were intended to test procedures, diagnostic equipment, and the experimental apparatus. Impact velocities were limited to 0.1 km/sec on the KC-135, as compared to the typical lunar impact velocity of 15 km/sec; these low velocities were dictated by safety considerations in these early experiments, not by technological limitations. Nevertheless, some important conclusions can already be made on

the basis of these early results: (1) Impact cratering experimentation in low-gravity environments is not only possible but practical. In no case were insurmountable difficulties encountered, and the data quality is high. (2) When all other conditions were kept as constant as possible, crater sizes did indeed increase as the g-level dropped. The results agree well with theoretical predictions. (3) The time taken for craters to grow as a function of the g-level had the correct qualitative trend — i.e., it takes craters longer to form in weaker gravity fields — but displayed a considerable quantitative divergence from the predicted relationship. This disparity could be caused by poor statistics from the small number of reduced-gravity experiments currently available, or it could represent a real difference between theory and reality. More experiments are being planned to evaluate the two possibilities.

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A crater being formed in a sand target during an experiment at 0.4g. Sequencing and digital data recording are performed with the computer.



Photographic and Television Enhancement in Support of the STS 51-L Investigation

PI: David E. Pitts/SN3
Reference OSSA 20

Photographic and television (TV) data formed a primary source of information on the cause and related sequence of events of the Space Transportation System (STS) 51-L accident. The visual analysis subteam was formed as an ad hoc organization to perform the photographic and TV data analysis at the Johnson Space Center (JSC). Accurate image interpretation required a knowledge of the objects and of phenomena contained in the images, as well as knowledge about image formation, processing techniques, and enhancing techniques.

To optimize the image information extraction process, teams of image interpreters and engineers were formed to analyze all the available data. Analysis and photoenhancement activities were performed at JSC and assigned to nationally recognized government and industrial laboratories to increase thoroughness and objectivity. The mission timeline was broken into eight parts to ensure thoroughness and to describe the significant events: (1) characterize smoke at launch, (2) search for continued smoke, (3) determine time and location of initial flare, (4) identify first evidence of hydrogen leak, (5) characterize right solid rocket booster (SRB) motion relative to stack, (6) characterize vehicle breakup dynamics, (7) characterize postexplosion condition of SRB's, and (8) examine underwater and salvage photography for critical evidence.

Much of the engineering hypothesis testing required a determination of the time and the location of an event. Timing was determined by using an Interrange Instrumentation Group (IRIG)-B code placed on the film products during exposure. An exact location was determined by superimposing hidden-line and wire-frame computer-aided drawing/camera (CAD/CAM) drawings upon enhanced digitized images. The CAD/CAM systems incorporated the location of the camera and the best estimated trajectory from STS 51-L in order to produce a vector image of the STS 51-L stack that represented the view from that camera position. This vector image was read into the JSC image processing system from digital tape and was mathematically registered to the digitized and enhanced three-color photograph by using a tiepoint registration routine that preserved axis isotropy by allowing changes only to scale, transla-

tion, and rotation. Using this approach with several camera positions (viewing angles), researchers determined the location of the burnthrough in the right SRB to be near the aft attachment ring at an angle of $315^\circ \pm 10^\circ$; the recovered debris showed that the burnthrough extended from 296° to 318° .

Numerous other studies involved the manipulation of CAD/CAM drawings with the image analysis system. Among these were the movement of the right SRB relative to the stack just before the explosion, the dynamics of the SRB's after the explosion, and the location of the smoke puff at launch. Conclusions reached in all of these studies at JSC were corroborated by other national laboratories. Additional information can be obtained from STS 51-L JSC Visual Data Analysis Sub-Team Report, JSC-22175, volumes I and II.

Digitized photograph from camera E207, frame 42, on which a computer-aided hidden-line drawing is superimposed, showing the location of the flame between the right SRB and the external tank, near the aft attachment ring.



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Aeronautics and Space Technology

Summary

Office of Aeronautics and Space Technology

Summary

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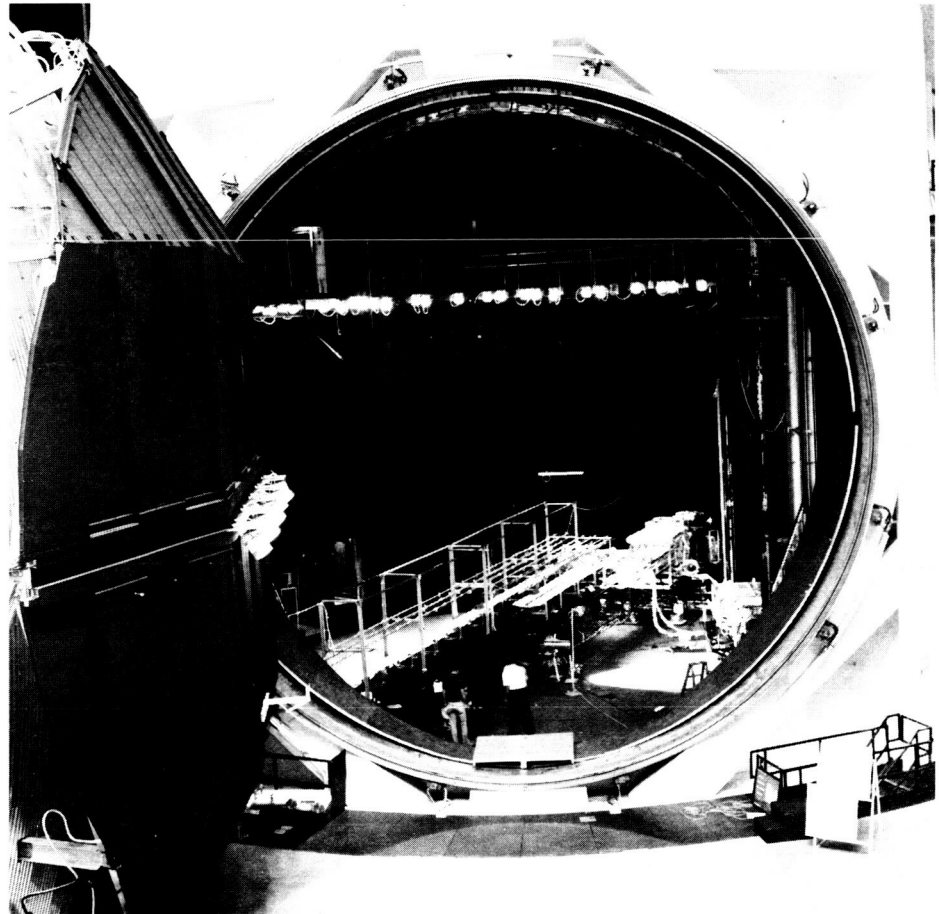
Introduction

The Lyndon B. Johnson Space Center (JSC), through the research and technology (R&T) programs funded by the Office of Aeronautics and Space Technology (OAST), has continued to provide sound analytical evaluations for a variety of technological issues. During fiscal year (FY) 1986, JSC provided support for a number of activities, which were primarily sponsored by the Space R&T Base Program (UPN 506) and the Systems Technology Program (UPN 549). In addition, the Aeronautics R&T Base Program (UPN 505) provided complementary funding to the Space R&T Base Program for continued support in advanced information systems technologies.

Generally, the R&T activities are centered around projects developing technological readiness in areas of advanced life support systems (namely, thermal management), composite materials, communication systems/telemetry data, human factors technology (as it relates to man/machine systems interface), space flight vehicle control systems, systems analysis (regarding proposed lunar/Mars manned missions), and the development of a closed-loop life support system. Likewise, JSC continues to provide the overall integration management and program planning in support of the National Space Transportation System (NSTS) Orbiter Experiments (OEX) Program.

Space and Energy Conversion

The JSC participated in two projects under the sponsorship of the Space and Energy Conversion R&T Program (formerly Thermal and Power). These programs provide the thermal management of large spacecraft systems and of crew support and air revitalization processes. The objective of the thermal management activity is to develop the technology



First integrated two-phase thermal management system thermal vacuum test in JSC chamber A.

for a system with multihundred-kilowatt capacity that can operate much like a public utility and thus can easily be expanded and adapted to accommodate increasing needs. Key technologies are the development of a two-phase, constant-temperature heat transport bus with contact heat exchangers and modular space-constructible heat pipe radiators. A prototype that has undergone extensive testing at the JSC vacuum chamber demonstrated successfully the viability of the two-phase system management concept.

Likewise, efforts have been expended in air revitalization techniques to

accomplish oxygen reclamation by employing electrochemical carbon dioxide removal technology. Electrolysis of carbon dioxide is a desired goal to recover the metabolic oxygen in future long-duration space missions. Research activities have centered around the various elements of an electrochemical depolarized carbon dioxide cell technology to increase process efficiency and flexibility. Currently, three different cell types are being fabricated and will subsequently be parametrically and life tested. The JSC is developing the thermal management and the air revitalization process

technologies as part of the Space Station Program.

Materials and Structure

Composite materials are being used for space applications on an increasing scale. In orbit, these materials are exposed to potentially damaging hypervelocity impacts from meteoroids and orbital debris. To evaluate the various composite materials, researchers used experimental data from the light-gas gun at the JSC Orbital Debris Impact Laboratory to develop math models capable of predicting the hypervelocity impact crater growth. Verification and refinement of the model predictions have been accomplished incorporating a new custom-designed, ultra-high-speed, rotating mirror framing camera. Further evaluations will be accomplished using more massive, spherical projectiles and incorporating the camera diagnostic capability.

Space Data and Communication

In 1983, JSC established a Beta Test Program for the Ada computer language. The communication and tracking systems technologies have been closely coordinated with the Beta Test Program to ensure their readiness for the upcoming Space Station Program. Efforts have been expended in analyzing Ada-related issues such as the capability of mixing Ada with other languages, the use of Ada in real-time applications, the Ada run-time environment, and the software tool set required for effective Ada software development and maintenance. As a result of these efforts, Ada has been selected for the Space Station Program.

Information Science

The primary language used with the Space Shuttle onboard systems is HAL/S. The HAL/S Language Control Board objective is to provide language support for the standard HAL/S compiler, tools, and documentation. A number of objectives are currently in progress and include developing an interactive debugger capability, developing an interactive interface between maintainers and compiler, archiving historical files and documentation, and evaluating the possibility of converting the BYRON language to Ada.

Human Factors

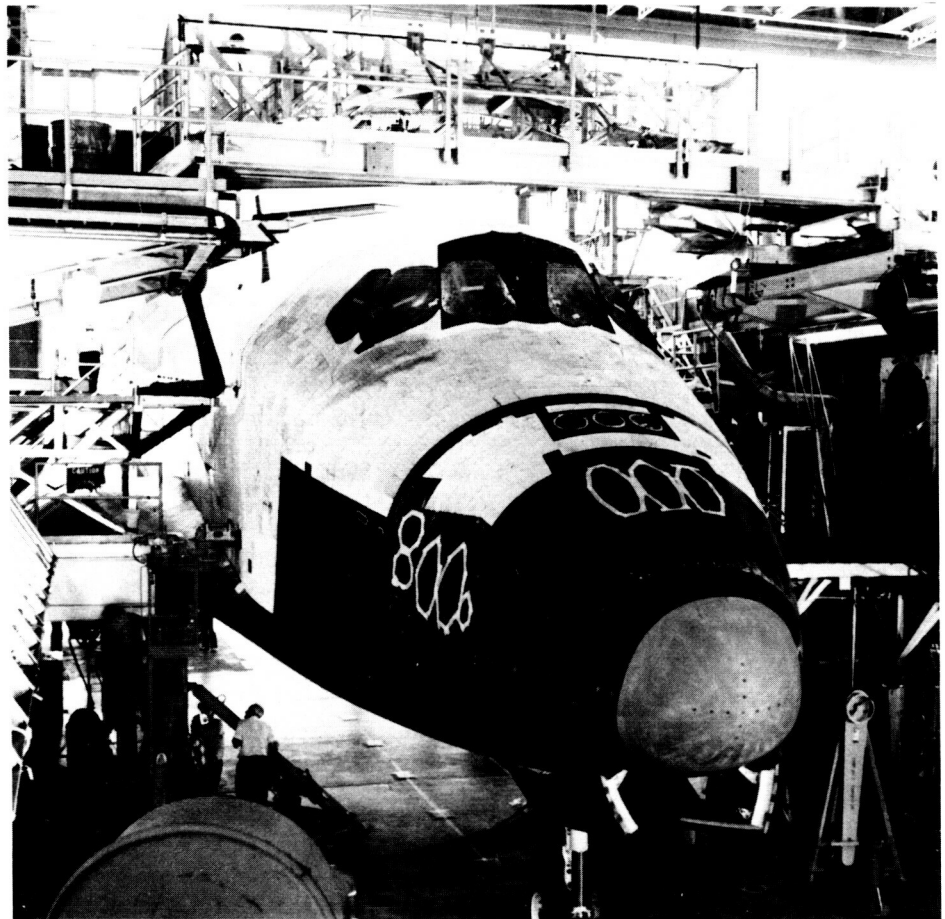
Human factors research is focused on the development of technologies that will lead to increased efficiency of man/machine interaction and thus increase man's effectiveness in space. A major part of this effort is in developing methods and techniques to ensure proper design integration of humans with various machine systems. Techniques for modeling human movement and strength capability are being developed for use in Space Station design.

A second area of research is the concern with multiple aspects of communication through crew station display and control consoles using various factors such as graphic formats, color coding, interactive display techniques, etc. The objective is to develop the use of graphic illustrations and diagrams in man/machine interfaces that will aid the controller in managing space subsystem elements.

Space Flight

The OEX Program is JSC's major activity in the STS R&T. The program was initiated in order to use the Space Shuttle as a flight research vehicle for acquiring data in the various technology disciplines that augment the space vehicle design R&T base. The JSC principal functions are to provide overall management and planning support to OAST, to accomplish experiment/Orbiter compatibility assessments, and to manage the physical integration of the experiments into the vehicle. Several OEX experiments have been flown aboard the Space Shuttle. In 1986, four major experiments were flown: the Shuttle Infrared Leeside Temperature Sensing (SILTS) Experiment, the Shuttle Entry Air Data System (SEADS) Experiment, the Shuttle Upper Atmosphere Mass Spectrometer (SUMS) Experiment, and the Advanced Autopilot Experiment (AAPE).

Space Shuttle *Columbia* in preparation for flight STS 61-C.



The SILTS experiment, sponsored by the Langley Research Center (LaRC), is installed on top of a vertical stabilizer in a pod capped at the leading edge by a hemispherical dome. Within this dome is an infrared scanner that views the upper fuselage and the left wing through two silicon windows. High-resolution infrared imagery is obtained during entry and is the first data obtained for an entry vehicle under flight conditions. The information will be used to increase understanding of leeside aeroheating phenomena with applications in enabling less conservative thermal protection system design. The SILTS experiment was flown on STS mission 61-C on January 12 through 18, 1986, aboard the Space Shuttle Orbiter *Columbia*. Despite several problems on the first flight, 900 sec of wing imagery and 30 sec of fuselage imagery were obtained, and the data will be forthcoming in a report to be produced by LaRC. Suitable corrections of anomalies are underway and will be reported in appropriate forums.

The SUMS experiment obtains measurements of freestream atmospheric density during entry in the hypersonic, rarefied-flow regime. These measurements, combined with acceleration measurements from the companion experiment High-Resolution Accelerometer Package (HiRAP), allow the calculation of Orbiter aerodynamic coefficients in a flow regime previously inaccessible to experimental techniques. The SUMS also measures equilibrium gas composition at the inlet port and makes the experiment a pathfinder for future mass spectrometer applications in studying aerothermodynamic properties of the transition flowfield. With successive flights, the resultant data base will aid in development of analysis techniques and laboratory facilities for prediction of winged entry vehicle performance in hypersonic, rarefied flow. Also sponsored by LaRC, the major portion of the SUMS hardware was derived from a flight spare unit from the Viking Project upper atmosphere mass spectrometer (UAMS) system. It measures gases with mass numbers ranging from 1 through 50 (including hydrogen at the low end and carbon dioxide at the high end).

In order to accomplish accurate flight aerodynamic research, precise knowledge of vehicle attitude and state is

required. These data, commonly referred to as air data, include vehicle angle of attack, angle of sideslip, free stream dynamic pressure, Mach number, total pressure, etc. An evaluation of the Orbiter baseline air data system indicated that flight air data would not be available for speeds greater than approximately Mach 3.5 and that the accuracy of the available air data from that system would not satisfy aerodynamic research requirements. The SEADS was therefore developed under the OEX Program to make the measurements required for precisely determining the air data across the Orbiter's atmospheric flight speed range (i.e., hypersonic, supersonic, transonic, and subsonic Mach numbers) or from lift-off to 280 000 ft during ascent and from 280 000 ft to touchdown during entry.

The key to incorporation of the SEADS into the Space Shuttle Orbiter was the development of a technique for penetrating the Orbiter's reinforced carbon-carbon (RCC) nose cap to obtain the required pressure measurements. The SEADS nose cap penetration assembly evolved as a result of extensive design, fabrication, and test programs that evaluated high-temperature (greater than 2600° F) materials and configuration concepts. The coated columbium penetration assembly selected was then fabricated for installation in a specially modified baseline geometry nose cap. The SEADS nose cap contains an array

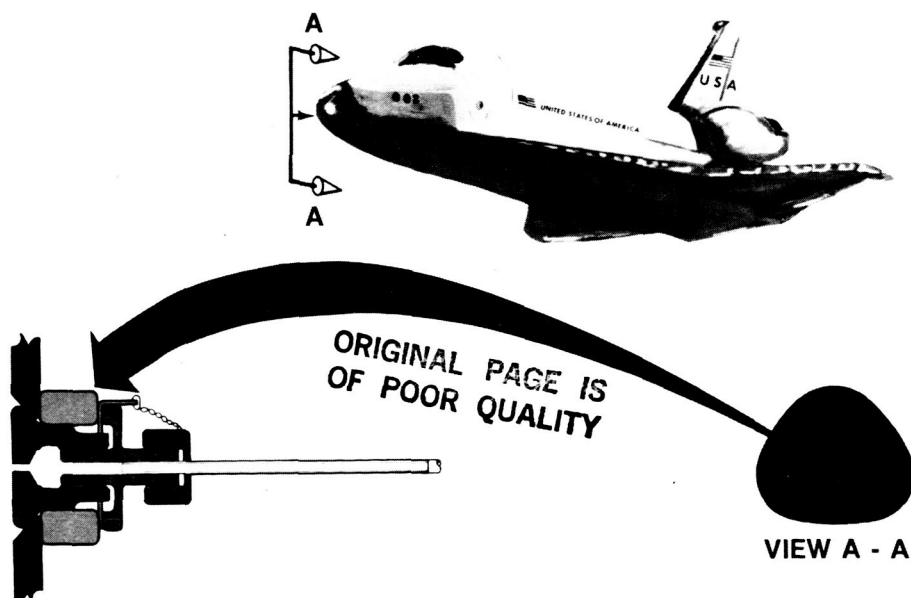
of 14 penetration assemblies, associated coated columbium pressure tubing, support structure, dual pressure transducers, and system monitoring instrumentation. Data from the SEADS pressure transducers are transmitted to the support system for OEX (SSO) and stored on the OEX recorder for postflight data analysis.

The SEADS was flown for the first time on *Columbia*, during STS 61-C on January 12 to 18, 1986. The SEADS data were recorded on the OEX recorder as designed. Data review indicates that all transducers remained operational and provided viable data. Postlanding inspection of the SEADS RCC nose cap and columbium ports revealed them to be in excellent condition. Visual inspection of the nose cone showed interesting flow patterns around the SEADS ports. Pressure testing of the SEADS pressure ports and tubes to verify structural integrity of the system proved that the system was tighter than it was before flight, as was expected. An estimated temperature of 2400° F was sustained with no evidence of port catalytic over-temperature. SEADS is ready for its second flight.

System Analysis

The JSC was invited to participate in the System Analysis R&T Program for involving activities that are beyond the current Space Station level of activities.

Configuration of SEADS in the Orbiter *Columbia*.



Initial efforts resulted in a review of the technologies that will require enhancement to support advanced programs. The following four topics were then selected for additional development:

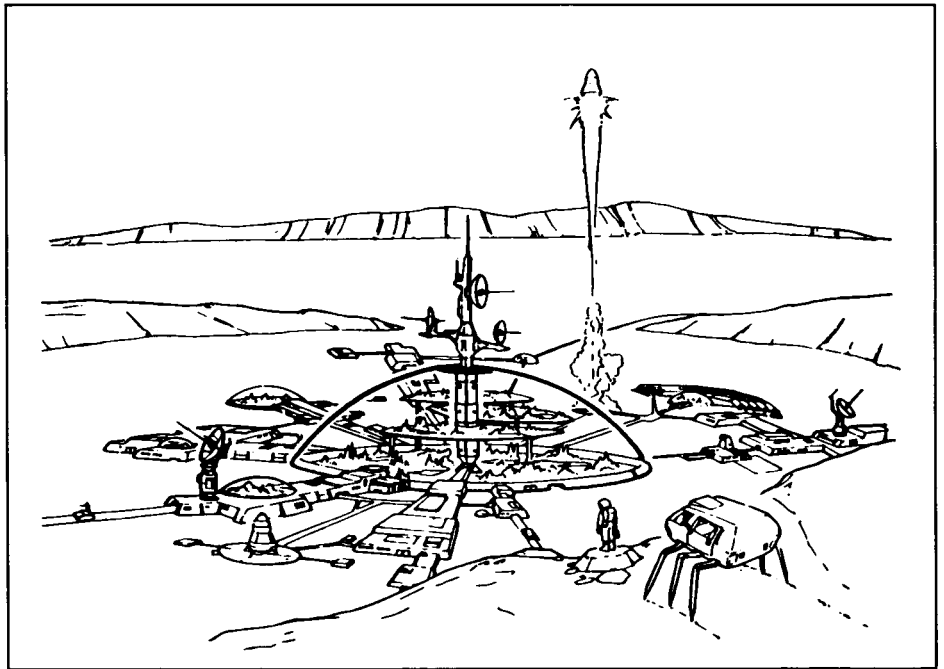
1. In-flight training for a manned Mars mission
2. The use of lunar materials for construction on the Lunar surface
3. Food production on lunar and martian surfaces
4. In situ resources utilization

Activities have already begun in these areas; however, results from these efforts are not expected to be documented until FY 1987.

Systems Technology

The current approach for the control of subsystems in manned spacecraft is highly labor intensive for the flight crew and for ground support personnel. A permanently manned Space Station will require a high degree of automation for the control of its systems and subsystems to reduce significantly the demand for monitoring the control. Efficiently organized local and archival data storage and the rapid retrieval and display of subsystem status will be required to maintain operations across the various subsystems. A program has been completed that demonstrates the technology now available to allow generic automation techniques to be applied in controlling spacecraft subsystems.

Conceptual lunar base operations.



Aeronautics and Space Technology

Significant Tasks

Two-Phase Thermal Management System Component Development

TM: Richard C. Parish/EC2
Reference OAST 1

The use of liquid and vapor phases of a thermal control working fluid for spacecraft thermal management has been studied by various NASA centers for several years. Recently, Space Station designers have baselined two-phase systems for heat acquisition and transport aboard the Space Station vehicle and associated free-flying platforms because of the obvious benefits these systems exhibit in reduced pumping power, system isothermality, and heat load flexibility. There are, however, uncertainties in the design process because of the limited amount of information available on liquid/vapor flow and heat transfer characteristics in a reduced-gravity environment.

To enhance the understanding of fluid behavior in a two-phase thermal management system (TPTMS) in a micro-g environment, the Johnson Space Center (JSC) initiated an effort to create a test stand that is capable of being flown aboard the JSC KC-135 aircraft equipped to fly reduced-gravity parabolas and that is also suitable for

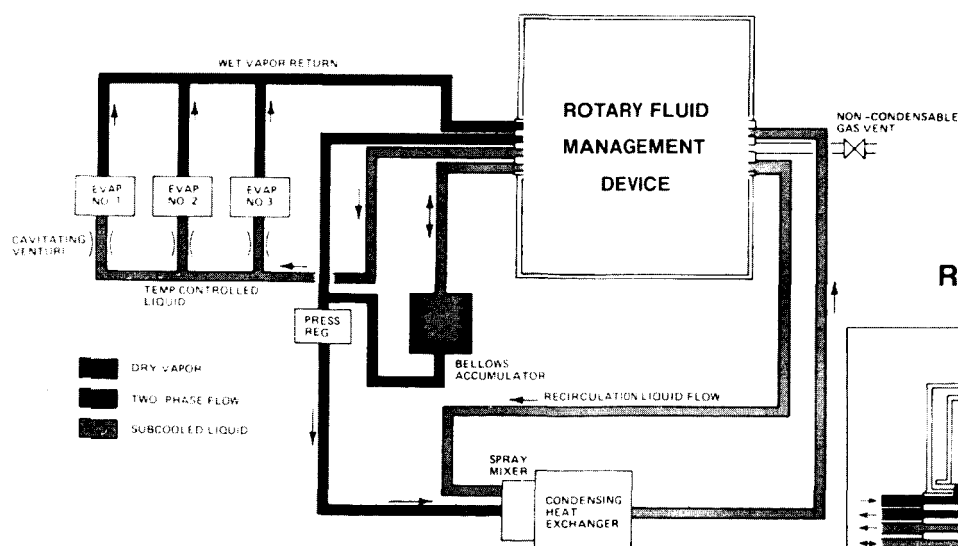
ground testing in JSC laboratory facilities. This test stand, depicted in the figure, will include components of a candidate TPTMS and will enable measurement of pressure drop, measurement of component thermal characteristics, and visualization (i.e., high-speed filming) and measurement of liquid/vapor flow phenomena. The test stand will include the basic components required of a two-phase transport loop such as evaporator, condenser, pump, accumulator, and pressure control valve.

The pump being used is a developmental pitot, phase-separation pump known as a rotary fluid management device. This type of pump handles varying ratios of liquid/vapor mixtures, separating the liquid from the vapor, returning liquid to the evaporator for heat load acquisition, and delivering vapor to the condenser for heat load rejection. Such a pump will allow the use of flow-through evaporators and will eliminate the need for active control of the liquid supply. The liquid/vapor mixture that exits the evaporator in the wet vapor return line will be the focus of attention during ground and reduced-gravity testing to assess various two-phase fluid flow phenomena.

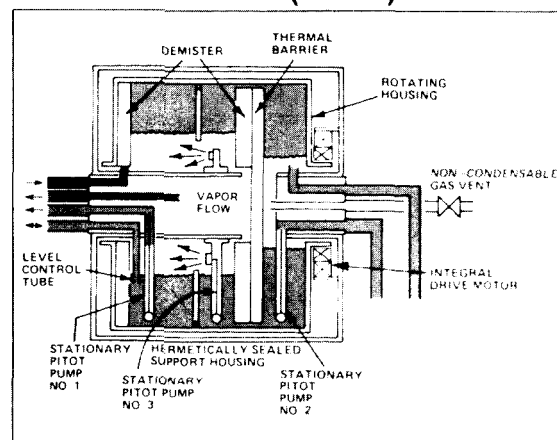
High-speed filming and high-resolution pressure drop measurements will be accomplished in a 17-ft-long transparent line section to evaluate normal versus reduced-gravity flow characteristics in the transport lines. Condensation of the thermal working fluid (Refrigerant-114) will also be observed, filmed, and measured in an acrylic-covered condenser section. The initial flight of the TPTMS test stand was scheduled for December 1986. The test stand is intended to be available for subsequent flights aboard the KC-135 to allow testing of alternate component designs and to enable further data generation and evaluation.

As a result of the comparative testing between the laboratory and reduced-gravity aircraft environments, significant information should be extracted concerning the operation of the TPTMS in an Earth-orbit environment. Because only limited data exist regarding the effects of reduced gravity on liquid/vapor flow regimes, this experiment will improve the data base significantly and will provide confidence to the aerospace community on the utility of TPTMS's for future spacecraft.

Two-phase thermal management test stand.



Rotary Fluid Management Device (RFMD)



Thermal Management for On-Orbit Energy Systems

TM: J. Gary Rankin/EC2
Reference OAST 2

Manned and unmanned space platforms projected for the 1990's and later will produce electrical power levels of several hundred kilowatts. Efficient thermal management is mandatory because generation, transfer, and storage of the electrical energy needed for these applications will require the dissipation of huge quantities of waste heat. No low-cost, reliable orbital thermal management system capable of providing this level of heat rejection exists. Such a system would need to overcome limitations inherent in current system designs. Ways to increase energy capacity, reject waste heat, and provide power for a broad range of space applications necessitate an entirely new technical concept in thermal management.

The key to the thermal management concept lies in the creation of a thermal utility system, analogous to municipal public utilities, in which basic trunk lines are provided for individual customer integration. The system must be designed such that changes in location or usage load of individual customers have minimal effect on the utility's capability to serve the loads of the remaining customers. Such a centralized system would allow reduced operational and payloads integration costs, as well as reduced cost for all payload users, by having common instrument thermal designs. Keys to reduction in thermal management system costs include system modularity; subsystem integration; growth capability to very large satellites; volume and weight reduction; extended life by maintenance and replacement; and expansion of the thermal management technology base to provide simpler, more reliable systems.

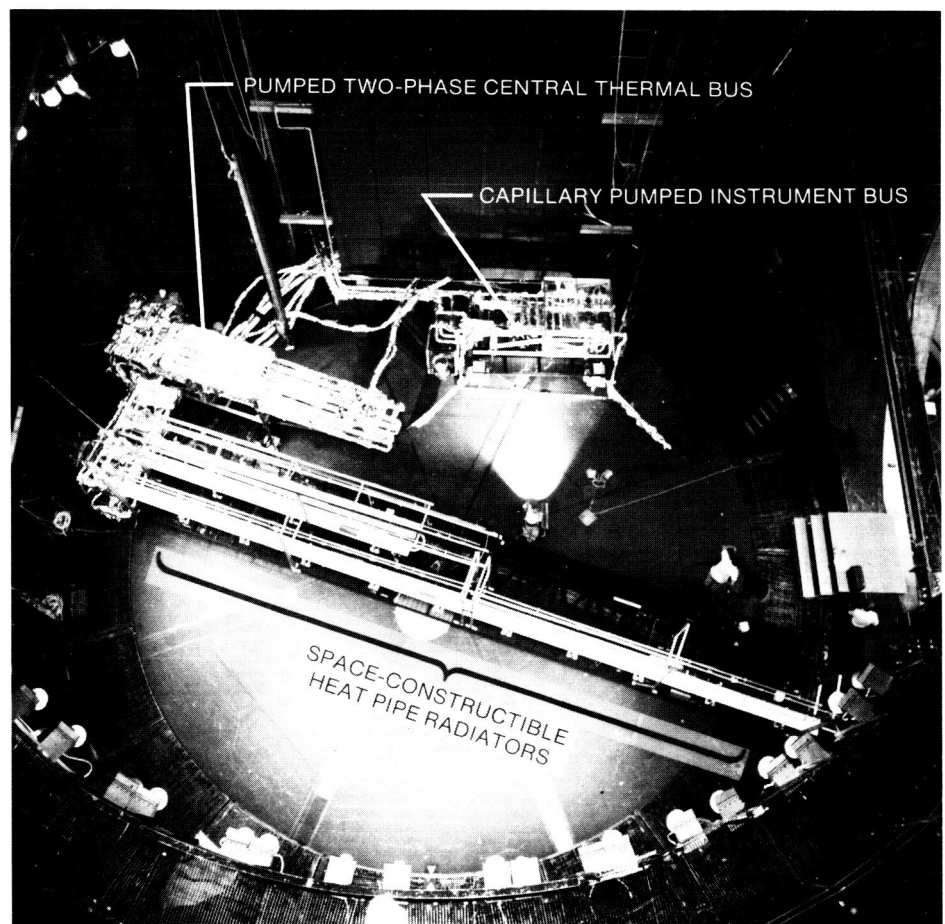
To meet these requirements, concepts involving two-phase (gas/liquid) heat transport devices are being developed. A centralized, pump-assisted, two-phase heat transport loop (or thermal bus) transfers heat by evaporation and condensation of the working fluid rather than by sensible heat changes of a single-phase cooling fluid. This loop operates at an almost constant temperature over its entire length, making users unaffected by their order of placement around the loop. Such a thermal bus is capable of transporting large thermal loads over long distances with pumping requirements that are minimal compared to single-phase system requirements.

A complete 25-kW, pumped, two-phase, thermal bus system has been designed. This system contains five separate evaporators of different types. Four separate but identical condensers provide the heat sink by allowing a contact interface with either simulated or actual

high-capacity heat pipe radiator elements: Fifty meters of both vapor and liquid transport lines are included to be representative of Space Station dimensions. The system (minus one of the evaporators) has undergone extensive testing at the NASA Johnson Space Center (JSC) in ambient and thermal vacuum environments using Freon-11 as the working fluid. Integrated two-phase system thermal vacuum testing also included an instrument pallet thermal bus developed by the Goddard Space Flight Center for delivering heat to the central bus and included full-size, high-capacity heat pipe radiators for providing the heat sink to the bus.

This system-level testing has successfully demonstrated the viability of the two-phase system thermal management concept for future space missions. Additional testing will be conducted at JSC with the fifth evaporator installed and with ammonia as the two-phase working fluid for even higher thermal performance.

Layout of integrated two-phase system thermal vacuum test.



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Direct Electrolysis of Carbon Dioxide for Oxygen Reclamation

TM: Robert J. Cusick/EC3
Reference OAST 3

Breathing oxygen (O_2) must be recovered from metabolic carbon dioxide (CO_2) to reduce the spacecraft logistics penalty for long-duration manned missions. An air revitalization process to accomplish O_2 reclamation removes the CO_2 from the cabin atmosphere by any one of several methods and breaks the CO_2 molecule into solid waste carbon and metabolic breathing O_2 . Advanced techniques, well-developed to date, involve a two-phase liquid/gas process of reclaiming the O_2 in the form of water (H_2O) followed by electrolysis to O_2 and hydrogen (H_2) at a voltage of 1.5 to 1.6 V.

Another technique to reclaim O_2 is a single-phase, fluidic gas process for directly electrolyzing the collected CO_2 to O_2 and carbon monoxide (CO) at a voltage approaching 1.0 V using a solid oxide zirconia (ZrO_2) electrolyte. Operation at $1000^\circ C$ virtually eliminates the high overvoltage inherent with low-temperature electrolysis cells and thereby offers a potential power savings. The single-fluid-phase nature also offers an advantage of simpler mechanical hardware with fewer moving parts for application in micro-g operations.

Typical electrolysis cells consist of, as a minimum, three discrete functional parts: the anode, the electrolyte, and the cathode. These parts require some method of bonding or joining and thereby incur additional contact resistance and resultant higher operating cell voltage. At the high operating temperature of a solid oxide CO_2 electrolysis cell, the typical design is further complicated by the requirement for several high-temperature seals. This fuel cell technology transfer which originally began with the Department

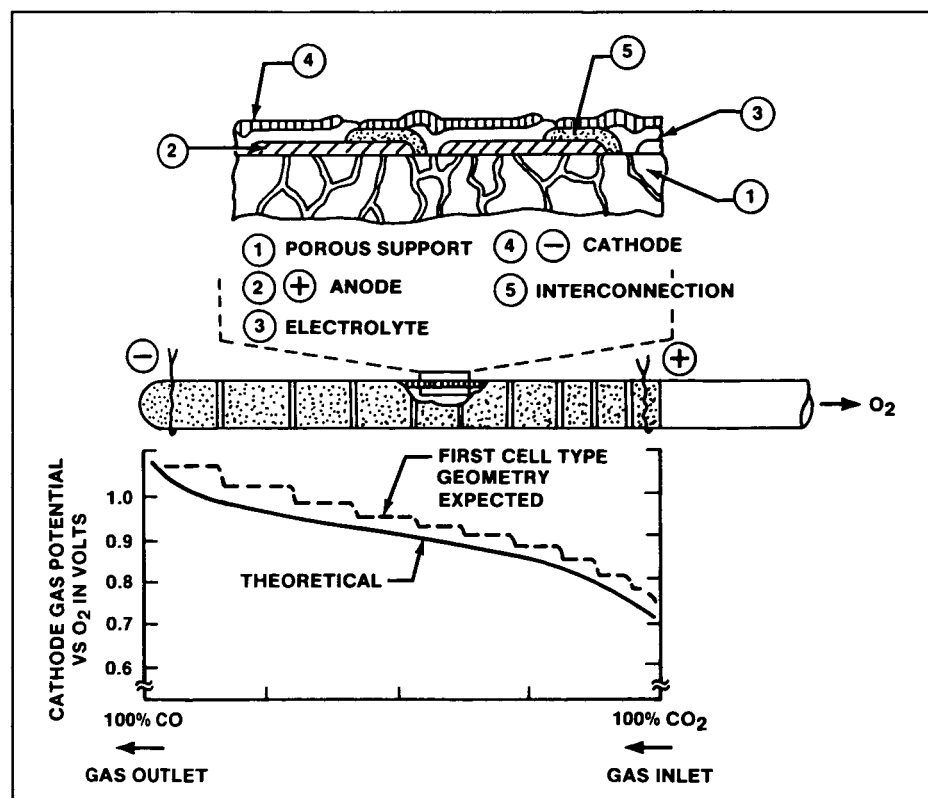
of Energy offers a single unitized cell of which the three functional parts, deposited on a porous ceramic tubular support, jointly form the sealing function in addition to their primary functions of carrying current and permitting conduction of O_2 as an oxide ion.

The unique property of stabilized ZrO_2 to conduct electricity at elevated temperatures, exclusively through the migration of oxygen ions, is the basis of the solid oxide CO_2 electrolysis cell. Thin electrode and electrolyte layers, 4 mils or less, are formed in the novel cell fabrication process of electrochemical vapor deposition. A typical cell tube and exploded view are illustrated. The CO_2 is electrolyzed to O_2 and CO. The CO is reduced to solid carbon (C) and CO_2 by another air revitalization and CO_2 reduction process. Another key feature offered by the CO_2 electrolysis cell is the direct electrolysis of metabolically produced water vapor to O_2 and H_2 , thereby yielding complete O_2 reclamation from the crew's metabolized CO_2 and H_2O byproducts.

Three different cell types are currently being fabricated and will subsequently be parametrically and life tested, with destructive micrographic analysis following the test. All three cell types are fabricated on a tubular porous ceramic support tube. The first type consists of many banded cells of 0.5- to 2-cm active width, electrically connected in series. Oxygen is generated, evolves from the anodic inside of the tube, and is maniout to the cabin atmosphere from a cell tube bundle.

The second cell type is a tubular single cell along the entire active tube length of 30 cm. A compact, cubic-close-packed arrangement can be achieved in a cell bundle buildup that can accommodate series as well as series/parallel connections, thus increasing the associated reliability of this cell geometry. The third cell type is also a tubular single cell, but the cell interconnection path is not a single longitudinal one of the second cell type but rather is made of several bands around the cell tube.

Solid oxide electrolyte cell structure.



Hypervelocity Impact Studies of Composite Materials

PI: Jeanne Lee Crews/SN12
Reference OAST 4

Composite materials are being used for space applications on an increasing scale. In orbit, these materials are exposed to potentially damaging hypervelocity impacts from meteoroids and orbital debris. The relative impact velocities can range from 1 to 16 km/sec for orbital debris and from 11 to 72 km/sec for meteoroids.

Extensive research into the hypervelocity impact resistance of metals and metal alloys has been conducted in the past. Mathematical models relating the extent of damage to impact velocity, projectile/target geometry, and material properties of projectile and target have been developed for these metallic materials based on extensive experimental data. Similar research on composite materials has been lacking. Such a study of graphite fiber composites is being conducted at the Johnson Space Center using the small light-gas gun in the Orbital Debris Impact Laboratory to obtain experimental hypervelocity impact data.

The University of Texas is performing the data analysis on the test samples by using an ultrasonic C-scanner to determine the extent of the internal damage and by visually examining the sectioned specimens to observe the crater, spallation, and delamination damage. The test samples to date consist of 16-, 32-, 48-, and 96-lamina plates (6 by 6 in.) of a quasi-isotropic graphite-epoxy layup (a quasi-isotropic layup was chosen to simplify the damage analysis). The test matrix consisted of varying the lamina count and the projectile density for impact velocities ranging from 4 to 7.5 km/sec.

A mathematical model for predicting the hypervelocity impact crater growth in a graphite-epoxy plate was developed and relates the time history of crater growth to the resistive pressure of the target material and to the resistive pressure of the radial expansion of the projectile during the penetration process. The model predicts crater growth reasonably well for the existing test conditions; however, the test matrix to date has been restricted to cylindrical projectiles of 5 mg mass. Further verification and refinement of the model

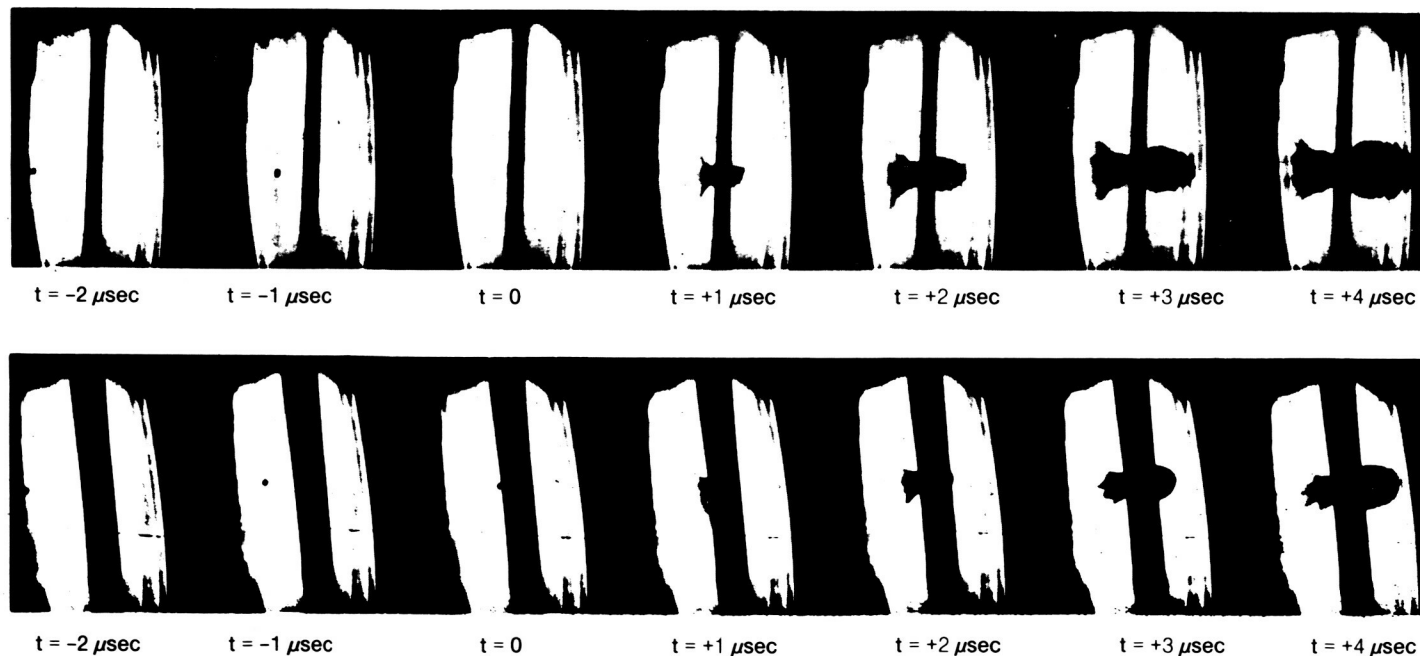
will be accomplished using more massive, spherical projectiles (mass of 70 mg) and incorporating a high-speed camera diagnostic capability.

A larger bore launch (4.3 mm) capability is currently being developed, and a new high-speed camera has recently been incorporated into the Orbital Debris Impact Laboratory diagnostic capabilities. The new camera system is a custom-designed, state-of-the-art, rotating mirror framing camera, using a laser diode for image illumination. The camera is capable of exposing 80 frames of 35-mm infrared film at 2×10^6 frames/sec. Even at that framing rate, conventional illuminating systems were not fast enough to "freeze" a 300- μ m particle traveling at speeds in excess of 7 km/sec. The 860-mm, 100-W laser diode used for this system has a pulse duration on the order of 5 nsec.

The larger bore launch capability will allow the launching of aluminum spheres as large as $\frac{1}{8}$ -in., and the high-speed camera will provide the exact state of the impacting projectile, the exact velocity of the projectile at impact, the velocity and shape of the ejecta (front), and the projectile/shield plume growth (rear).

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Examples of high-speed framing camera capabilities. Top: A 0.057-in. graphite-epoxy panel being impacted by a 5-mg nylon slug (0.07 by 0.07 in.) traveling at a velocity of 5.99 km/sec. (Exposure time = 5 nsec.) Bottom: A 0.04-in. 6061 aluminum panel being impacted by a 4.99-mg slug (0.07 by 0.07 in.) traveling at a velocity of 5.8 km/sec. (Exposure time = 5 nsec.)



Testing and Analysis of the Department of Defense Ada Language

TM: Stephen Gorman/FR12
Reference OAST 5

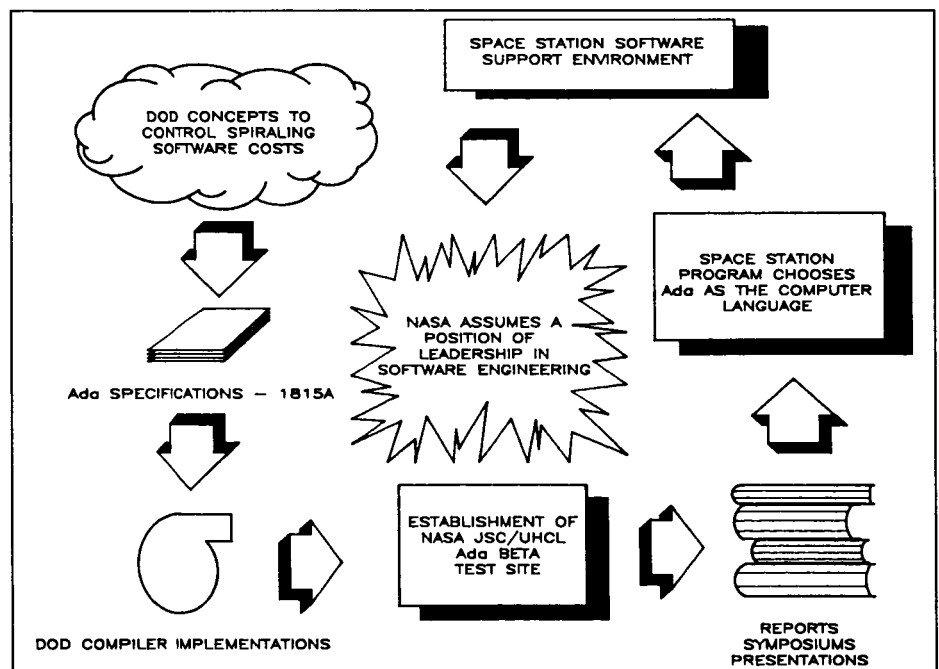
At the beginning of fiscal year (FY) 1983, the Johnson Space Center (JSC) established the Ada Beta Test Program with the University of Houston at Clear Lake (UH-CL). The period of performance was through June 31, 1986, and was completed this year. The purpose was to analyze the efforts of the Department of Defense (DOD) to manage the ever-increasing costs of software development and maintenance, with special emphasis on their high-order computer language, Ada. The UH-CL was joined on a voluntary basis by more than 30 different contractors studying various aspects of the Ada technology. NASA and UH-CL also employed contractors such as Softech and Intermetrics to study specific subjects of interest more closely.

This activity has had extraordinary success in transferring technology to mainstream NASA activity. The Space Station Program has recently specified that all operational Space Station software will be developed in Ada. The JSC and UH-CL have jointly sponsored two minisymposiums on current Ada research and one full-scale symposium entitled, "The First National Conference on Ada Programming Language Applications for the NASA Space Station," which drew more than 400 participants. The results presented in these symposiums as well as the continuing consultations and presentations by task personnel have helped to provide the confidence required for the Space Station Program Office to move ahead as it has.

Examples of Ada research at JSC for FY 1986 are the development of a benchmarking capability for assessing compiler implementations; evaluation of existing Adarun-time environments; development of extended run-time environment requirements for the anticipated Space Station distributed computer configuration; study of the common APSE interface set (CAIS) issues; analysis of Ada tools developed for DOD and available in the DOD SIMTEL library; and definition of training issues specific to learning modern software engineering methodologies and to using Ada. Additional task personnel have assisted NASA in presenting concerns and issues at Ada boards and committees such as the Ada Run-Time Working Group, Ada Board, Kernel Interface Team, CAIS Working Group, and others.

The Request for Proposal (RFP) for the Space Station Software Support Environment states, "The Space Station Program has adopted Ada as its primary software language. The full intent of Ada and its associated software engineering principles shall be required." This statement establishes Ada firmly as an important element of the Space Station Program. It also points out the logical area of concern for further NASA software-related research, which is in the area of new methods of software engineering and the establishment of state-of-the-art software development and maintenance environments. The focus of research must be expanded to encompass the entire software life cycle from conceptual design through sustaining engineering and eventual retirement of the software. To pursue this end, UH-CL is establishing the Software Engineering Research Center with anticipated joint participation from NASA.

Software engineering research interfaces.



HAL/S Intercenter Board

TM: Dave Sykes/FR24
Reference OAST 6

The High-Order Assembly Language for Shuttle (HAL/S) Language Definition and User Group, also referred to as the NASA HAL/S Board, was established in 1977 to provide language support for the standard HAL/S compiler, tools, and documentation. Its objectives are to maintain the standard compiler and documentation, to control change requests and discrepancy reports, and to improve user tools and interfaces in order to maintain compiler viability in evolving environments.

The technical objectives and the status of each for fiscal year (FY) 1986 are as follows:

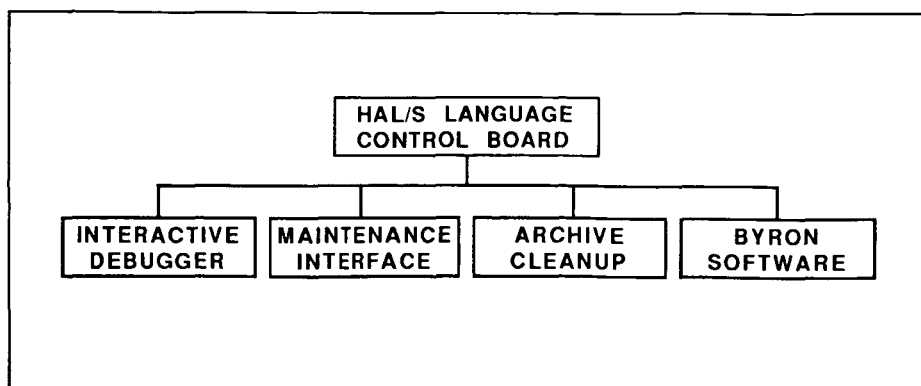
1. An interactive debugger is being developed to improve debugging HAL/S programs on the IBM 360 system. Coding was completed on the required commands; testing, however, was not completed. This program will be completed and delivered in FY 1987.

2. Development began on an interactive interface between the HAL compiler maintainers and the compiler. Requirements, design and program descriptions, and user guide documents will be produced. Interactive software will be coded and tested to allow automation of the compiler maintenance task. Coding and testing were completed on CLISTS and will allow much greater automation. This activity will continue in FY 1987 because automation will be completed in sequential steps, the first of which is not complete.

3. Organization of the HAL/S archives material to provide future maintainers a more reliable mechanism for accessing historical files and documents was performed. Documentation and tapes from several different locations were collected at a central library. The new collection was catalogued using an automated data base system. The library is now complete, and maintenance only will continue through FY 1987.

4. A program design language (BYRON) was applied to existing HAL/S code to analyze possible conversion to Ada. The HAL/S statements were integrated into BYRON code to test Ada development methodology with HAL/S. All coding and testing of the conversion of a HAL/S module to Ada using BYRON has been completed. The report of the findings of this task will be completed in early FY 1987.

Primary functions of the HAL/S Language Control Board.



Human Strength and Motion Modeling

TM: Barbara J. Woolford/SP34
Reference OAST 7

The Johnson Space Center is building a computerized model of human capabilities for use in spacecraft design and mission planning. This software will model human physical features such as size, strength, and motion. Current capabilities include specifying anthropometric percentiles and automatically constructing a properly sized human body. The motion modeling capabilities include automatic positioning of a body in a configuration to reach a specified object, given some restraint condition.

The most difficult parameter to account for is that of strength in zero g. Quantitative data are not available. It is known that the strength that can be applied in zero-g is partially a function of restraint type and also is greatly affected by whether the astronaut is working in shirtsleeves or in a pressurized space suit.

The instrument for measuring strength is the Cybex dynamometer, which records torque exerted while it controls the velocity at which the participant can rotate the tool. A constant velocity is required, because strength is also a function of the speed at which the motion is performed. The Cybex has been packaged in a waterproof container for use in the Weightless Environment Test Facility (WETF), and a stand has been designed to permit mounting the Cybex in the KC-135 aircraft for testing during parabolic flight with 30-sec periods of weightlessness.

The purpose of the experiment is to collect strength data on suited and shirtsleeved astronauts in three environments: the laboratory setting in 1g, the WETF in neutral buoyancy, and the KC-135 aircraft in true (but brief) zero g. This data will be of two types: single-joint rotation, such as elbow flexion or shoulder abduction, to provide data to the computer model; and complex motion, such as rotating an extravehicular activity (EVA) wrench, to provide operations data. The packaged Cybex has been flown on the KC-135 three times. Data from similar tests in the WETF will be collected for comparison and validation of WETF simulations.

The plans for fiscal year 1987 are to complete the test matrix and to incorporate the force capability data into the computer model.

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Astronaut Pierre Thuot exercises his right elbow joint in the KC-135 aircraft equipped to fly gravity-reduced parabolas. He is held in place by EVA foot restraints and does not have a handhold available.



Crew Station Human Factors

TM: J.T. Malin/EF
Reference OAST 8

The purpose of the Johnson Space Center (JSC) Human Factors Laboratory (HFL) is to examine user interaction with advanced display, control, and computer technologies. This project involves performing several research studies, collecting human performance data from users interacting with these technologies, and providing recommendations detailing how these technologies may be incorporated into spacecraft work stations to optimize the man/machine interface.

The approach taken was to develop a user needs/advanced technologies matrix from which 12 general research issues were derived. An issue was chosen (e.g., programmability/multifunctionality or voice recognition/production), and a literature search was performed. Specific experimental topics were chosen; experiments were designed; human performance data were collected and analyzed; and technical reports were prepared.

Six technical reports have been published, with topics ranging from user interaction with programmable display and control devices to the human factors of expert systems. The most recent area of investigation involves the electronic display of procedural information. A crew operations research work station, incorporating several types of display and control devices, and a user interface management system for the rapid prototyping and evaluation of human/computer interface efforts have been developed. The HFL is responsible for developing the human/computer interface design guide for the Space Station Program. Contacts have also been established with industry, the Department of Defense, and other NASA centers.

As a result of this program, human performance data have been input into the Space Station design. A facility with personnel devoted to spacecraft human factors has been established at JSC. Additionally, contacts through the HFL bring new technologies and information to JSC and to the manned space program.

In the future, researchers at the HFL plan to continue the research program through the examination of user interaction with multifunctional displays and controls and through the electronic display of procedural information. Additionally, researchers will begin to examine user interaction with intelligent computer systems. The user/computer interface rapid prototyping capability will be expanded.

HFL crew research operations work station (foam-core mockup).



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Advanced Autopilot Experiment

TM: Jerry Woodfill/EX3
Reference OAST 9

The Advanced Autopilot Experiment (AAPE) demonstrated a new class of autopilot incorporating a unique control approach that features real-time failure configuration and optimization. This approach employs an optimizing linear select algorithm and a multidimensional phase-space rotational and translational control law (an improvement over autopilots employing one or more two-dimensional phase plane control laws). Control systems based on this phase-space philosophy have potential applications in several vehicles for which fuel economy and rapid failure recovery are requirements. Autopilots in this class are adaptable to most spacecraft in which reaction control system (RCS) and/or control moment gyro effectors are used. Effectors do not need to be placed orthogonally and may be blended. The AAPE software was incorporated into the Space Shuttle software and resided in the Space Shuttle computer memory.

The experiment operated during the orbital flight phase of Space Transportation System (STS) missions STS 51-G and STS 61-B and resulted in fewer jet firings, reduced computer burden, improved vehicle response, less propellant consumption, and more flexibility.

On STS 61-B, a radar corner reflector (target) was deployed during an extra-vehicular activity by astronaut Woody Spring for use during stationkeeping exercises. By sighting an Orbiter television (TV) camera on the deployed target, astronauts could make a comparison of AAPE and primary flight system (PFS) control for a prescribed maneuver.

The target was constructed of flat aluminum plates which were stored in a crew cabin locker and erected into a sphere by a crewmember before deployment. Target deployment occurred during a loss-of-signal communication period but was recorded on Orbiter video so that quantitative assessments of maintaining position could be made after flight. In general, the ground observers noted a steadier position of the target on the TV monitor during AAPE control than during periods of PFS control.

When the target was deployed, the remote manipulator system camera was 10 ft from it. Cargo bay lights provided adequate illumination of the target during nightside passes. The crew reported that the reflective tape on the target enhanced visibility as the Orbiter separated from the target. The entire process of assembling, tethering, and deploying the target went smoothly and established a concept which may prove useful on future missions.

Initial testing of the AAPE (before target deployment) demonstrated such reliable operation that the planned 15 min of AAPE control were extended to 1 hr in order to observe vehicle handling qualities during maneuvers at the 35-ft stationkeeping distance. The switchover from PFS to AAPE software 15 min after target deployment was very smooth.

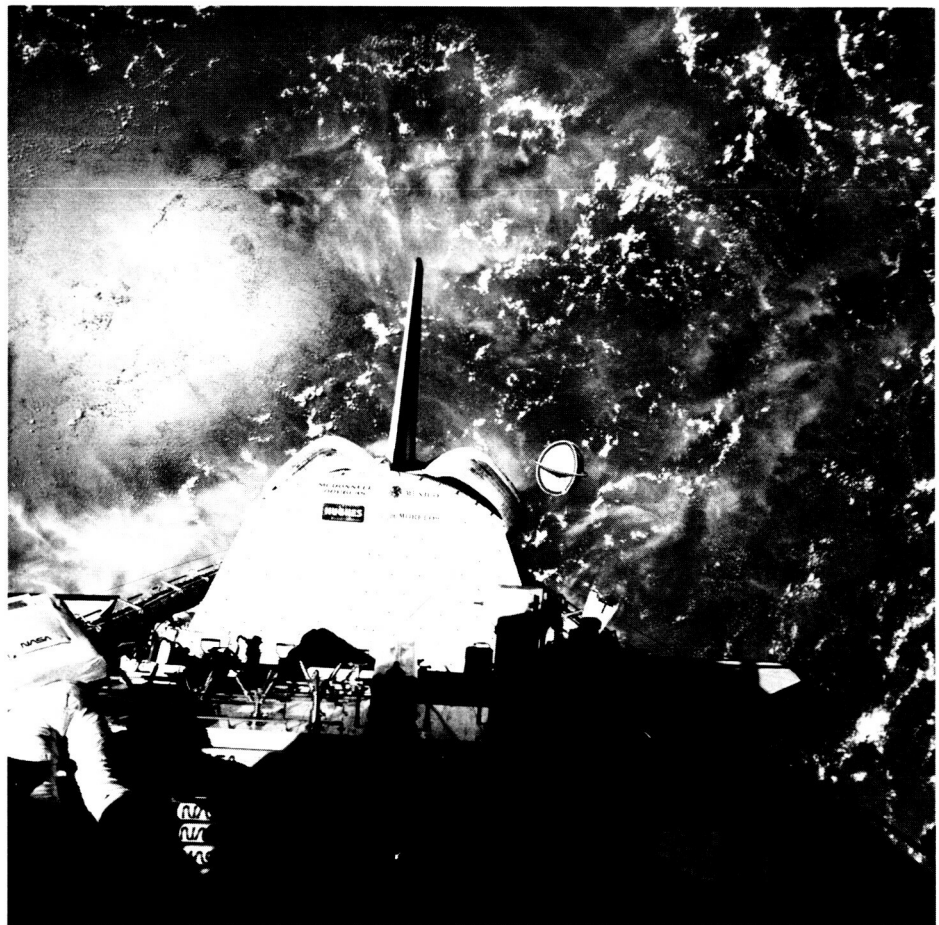
The AAPE controlled the vehicle for more than 30 hr during the mission and provided much greater confidence in

its use as an operational system. The crew reported that the AAPE performed one of the cleanest velocity-vector maneuvers ever run, that it held attitude tighter than the primary digital autopilot (DAP), and that with the AAPE, the problem of cross coupling between translation and rotation encountered with the primary DAP was lessened. The low-Z mode worked correctly.

Because of the AAPE's optimized use of a combination of vernier and primary thrusters for attitude hold (rather than selecting one or the other as the PFS does), the RCS fuel consumption was reduced between 10% and 20% for extended periods.

On STS 61-B, the Orbiter vernier thrusters were inhibited to provide a comparison with a 0.1° deadband test performed on STS 51-G. The AAPE maintained attitude to 0.07°/body axis, using approximately one-fifth the RCS propellant required by the PFS for control to only 0.5°/axis.

Radar corner reflector deployed as AAPE target during STS 61-B mission.



Automated Subsystem Control for Life Support Systems

TM: Frank H. Samonski/EC3
Reference OAST 10

The current approach for the control of subsystems in manned spacecraft is labor intensive both for the flight crew and for ground support personnel. A permanently manned Space Station will require highly automated control of its systems and subsystems to reduce significantly the demand for monitoring the control. Efficiently organized local and archival data storage and the rapid retrieval and display of subsystem status will be required to maintain operations across the various subsystems. A program has been completed that demonstrates the technology now available to allow generic automation techniques to be applied in the control of spacecraft subsystems.

To ensure the generic nature of the automated subsystem control techniques developed, an applications study was conducted to determine the controlling and monitoring requirements of three representative Space Station systems: the environmental control and life support system; the electrical power system; and the guidance, navigation, and control system. Based on the results of this study, a family of generic automation controllers was designed, and a specific configuration was selected for application to the air revitalization group of subsystems within the environmental control and life support system.

Four identical controllers were then fabricated: three to control and monitor the three subsystems within the air revitalization group — electrochemical carbon dioxide (CO₂) concentration, Sabatier CO₂ reduction, and acid electrolyte oxygen generation — and the

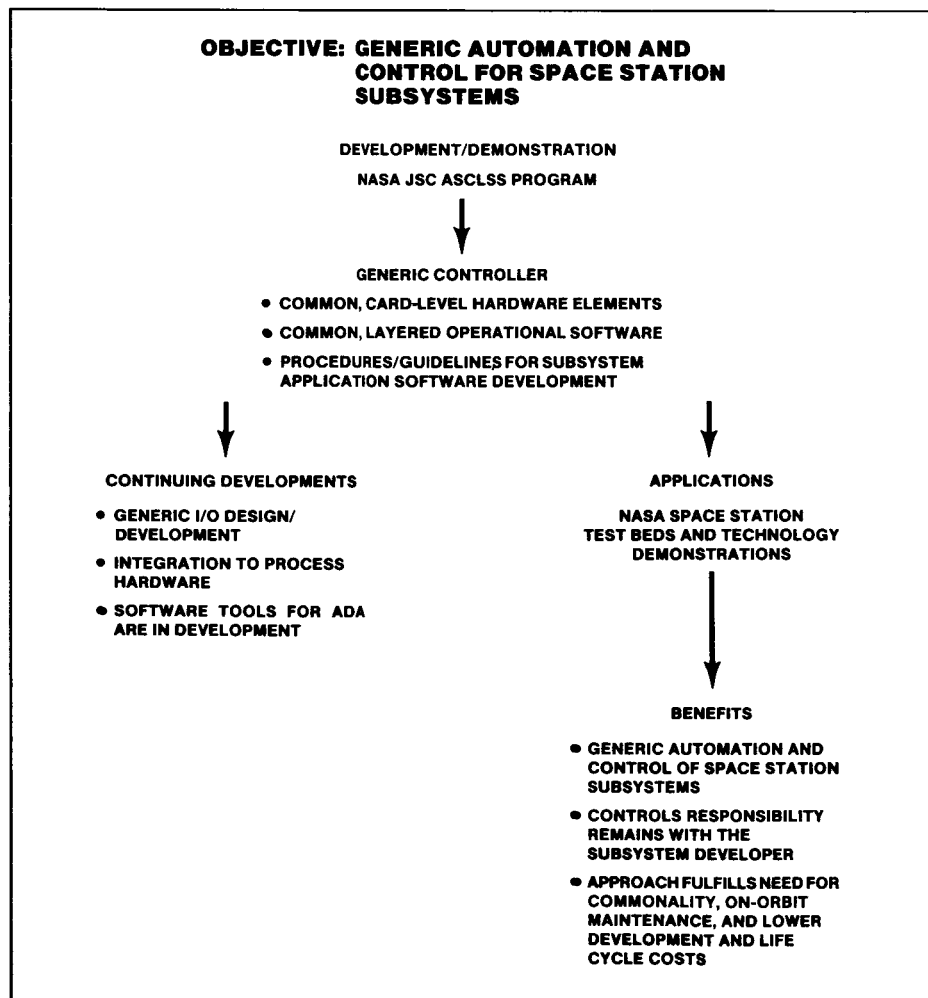
fourth to perform the supervisory and sequencing functions necessary for the three subsystems to work in an integrated manner to accomplish the atmosphere revitalization function. State-of-the-art electronics technology was employed in the generic controller and included the Military Standard 1750A 16-bit microprocessor, which uses a standard instruction set for software programming and a dual-redundant data bus for high-speed communications between the four controllers.

In parallel with the design and fabrication of the four controllers, process simulators were developed using three personal computers to emulate the chemical and electrochemical processes of the three subsystems. A fourth and more powerful personal computer was adapted to perform the man/machine interface functions, including the retrieval display of data and the command link for selecting various operating modes.

A unique approach was developed for the design and coding, in higher order language, of the software required. Referred to as a layered software structure, identical code was used in each of the four controllers to accomplish common functions such as data base management and systems control. The process control software, which is unique to each of the subsystems, interfaces with only the common systems control software and not directly with the subsystem simulators. Assembly language code was selected for the small fraction of software referred to as the operating system to maximize the speed of data acquisition, of data transmission, and of data base updating.

The fabrication of the controllers and the preparation of the software has been completed. A comprehensive acceptance test was conducted successfully, and the complete system was delivered to the Johnson Space Center in July 1986. Various system evaluation tests are being conducted to verify performance and to evaluate the dynamics in the transitions between the operating modes. Recommendations are being prepared to enhance the display of information to the operator and to examine the fidelity of the process simulators. A continuation effort is being planned and would replace one of the subsystem simulators with actual process hardware.

Space Station Technology Program automated subsystem control for life support system (ASCLSS).



Space Flight Advanced Programs

Summary

Office of Space Flight

Summary

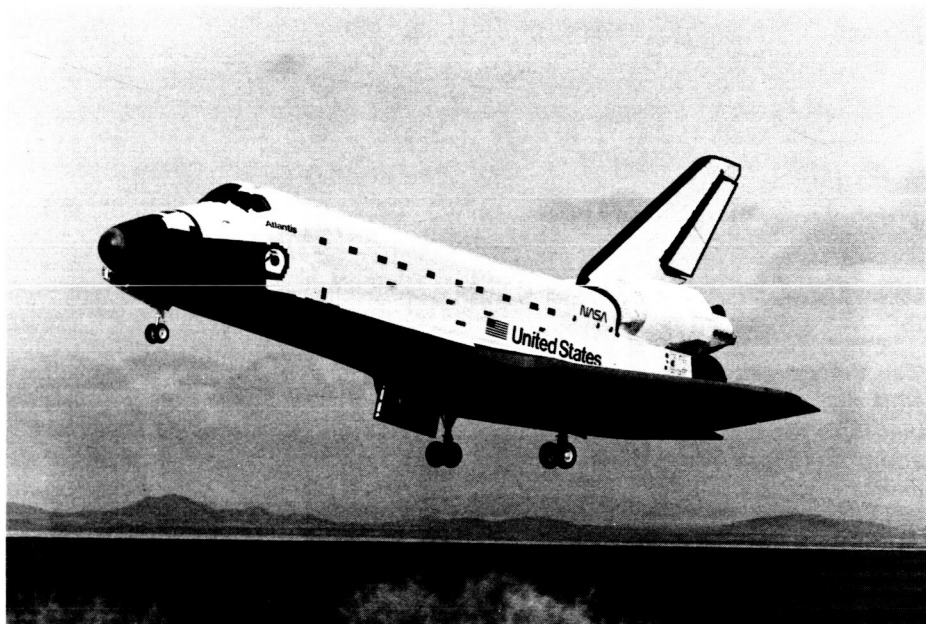
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Introduction

The Office of Space Flight (OSF) Advanced Programs activity is directed toward enhancing and expanding the National Space Transportation System (NSTS).

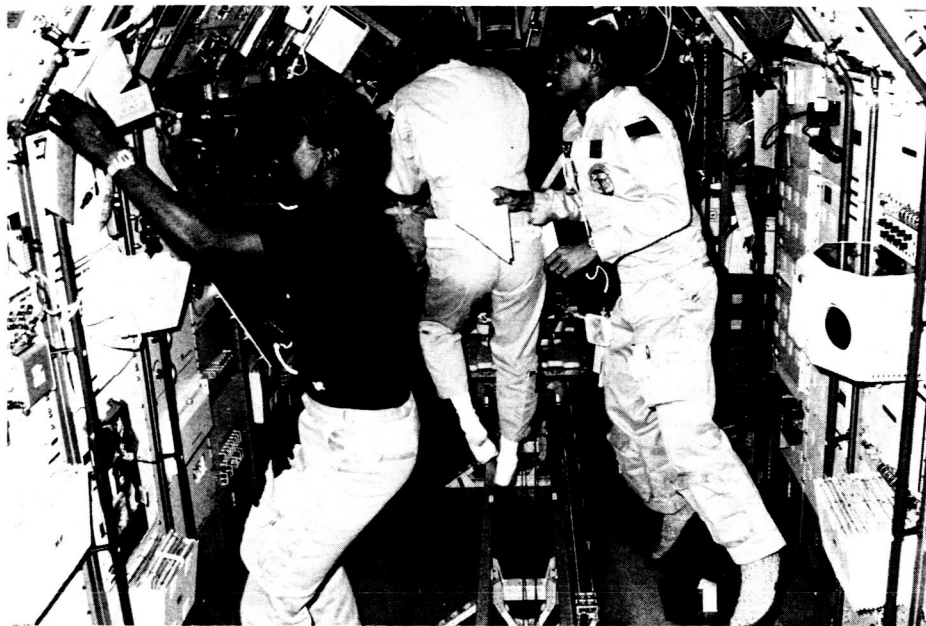
Early in fiscal year (FY) 1986, the maiden flight of the fourth Space Shuttle Orbiter, *Atlantis*, marked the completion of the initial STS fleet. The following mission, which was dedicated to the German Spacelab, highlighted international cooperation in the Space Shuttle Program. It was the first Space Shuttle flight to be chartered completely by another country, and it carried a record-breaking eight-member crew, two of whom were West German payload specialists. The Spacelab's experimental facilities were arranged according to scientific disciplines into "payload elements" which included melting furnaces, facilities for the observation of fluid physics phenomena, chambers to provide specific environmental conditions for living test objects, and the vestibular sled, which exposed the astronauts to defined accelerations in order to study the function of the inner ear. During the 7-day mission, 70 experiments in micro-g materials processing, life sciences, communications, and navigation were conducted with the scientific operations being controlled from the German Space Operations Center near Munich.

During FY 1986, the first construction of large structures in space was also demonstrated with two flight experiments. The Experimental Assembly of Structures in Extravehicular Activity (EASE) project consisted of six aluminum beams, each 12 ft long, and demonstrated assembly techniques in which the crewmembers moved about the structure as required. The Assembly Concept for Construction of Erectable Space Structures (ACCESS) project consisted of 93 tubular aluminum struts,



Space Shuttle Orbiter *Atlantis* landing after her maiden flight.

Guy Bluford, Ernst Messerschmid, Reinhard Furrer, and James Buchli performing experiments in the Spacelab module.





On-orbit assembly of the Assembly Concept for Construction of Erectable Space Structures (ACCESS) during mission STS 61-B.

with 1 in. diameter. The crewmembers, working from a fixed platform, assembled the struts into a 45-ft-long truss. In addition to the assembly task, the maintenance, and the repair, procedures were investigated by stringing flexible cable along the ACCESS truss to simulate the installation of electrical cables. The crewmembers also removed and replaced individual struts to demonstrate repair capability.

Four communications satellites were deployed, including two for foreign governments. Telephone, television, and wire services are being provided for Mexico by the Morelos-B satellite; a similar satellite, AUSSAT-2, was deployed for the Australian National Satellite System.

Advanced Space Flight Technology

Future space transportation missions, which will orbit planets with atmospheres, can obtain significant performance improvements (when compared to all propulsive concepts) by aerobraking within the atmosphere. In order to stimulate advances in the disciplines of aerothermodynamics, aerodynamics, and guidance, navigation, and control (GN&C), the aeroassisted flight experiment (AFE) has been proposed to fly onboard the Space Shuttle in 1992. The AFE is a NASA intercenter project which will provide the technology for an

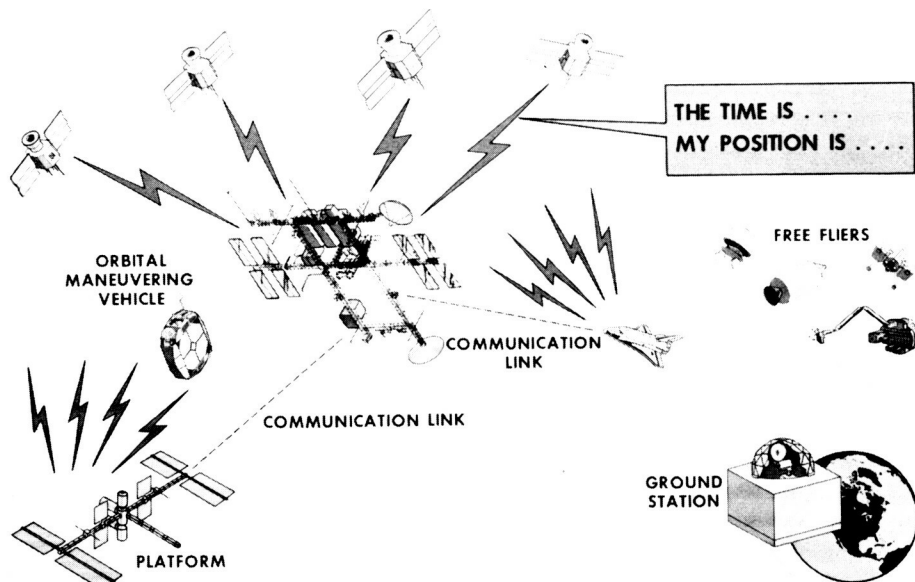
aeroassisted orbital transfer vehicle (AOTV). During the year, the elliptical, raked-off cone concept developed at the Johnson Space Center (JSC) was chosen as the AFE baseline configuration. The heatshield structure is planned to be conventional aluminum skin and stringer covered with thermal protection system tiles similar to those used on the Space Shuttle. Eleven scientific experiments are being integrated into the heatshield and carrier vehicle struc-

ture. Also under study are several atmospheric guidance algorithms which are being considered for use on the AFE. All concepts employ banking about the velocity vector to control motion in the vertical plane.

With the new flight vehicles, new techniques in GN&C are being developed to facilitate multiple-vehicle mission planning and operations. The newly developed automated rendezvous and proximity operations simulation software was developed as a tool for performing parametric analysis of rendezvous and proximity operations for a reference nonmaneuvering vehicle (Space Station or Orbiter) and as many as five maneuvering free-flyers. The six-degree-of-freedom (DOF) proximity mode offers a variety of attitude control regimes, a model of a relative position/attitude determination sensor, and the capability to correlate propellant expenditure by axis and function.

The simulation will model first-order error sources and environmental effects to the level necessary for making credible judgments about operational feasibility and for assessing subsystem performance requirements. An analysis of the global positioning system (GPS) has shown it to be capable of highly accurate spacecraft navigation, and it has been baselined in this role for future spacecraft designs. It can also be applied to nonclassical navigation functions. A series of studies has shown

The GPS will be able to supplement traditional spacecraft navigation systems.



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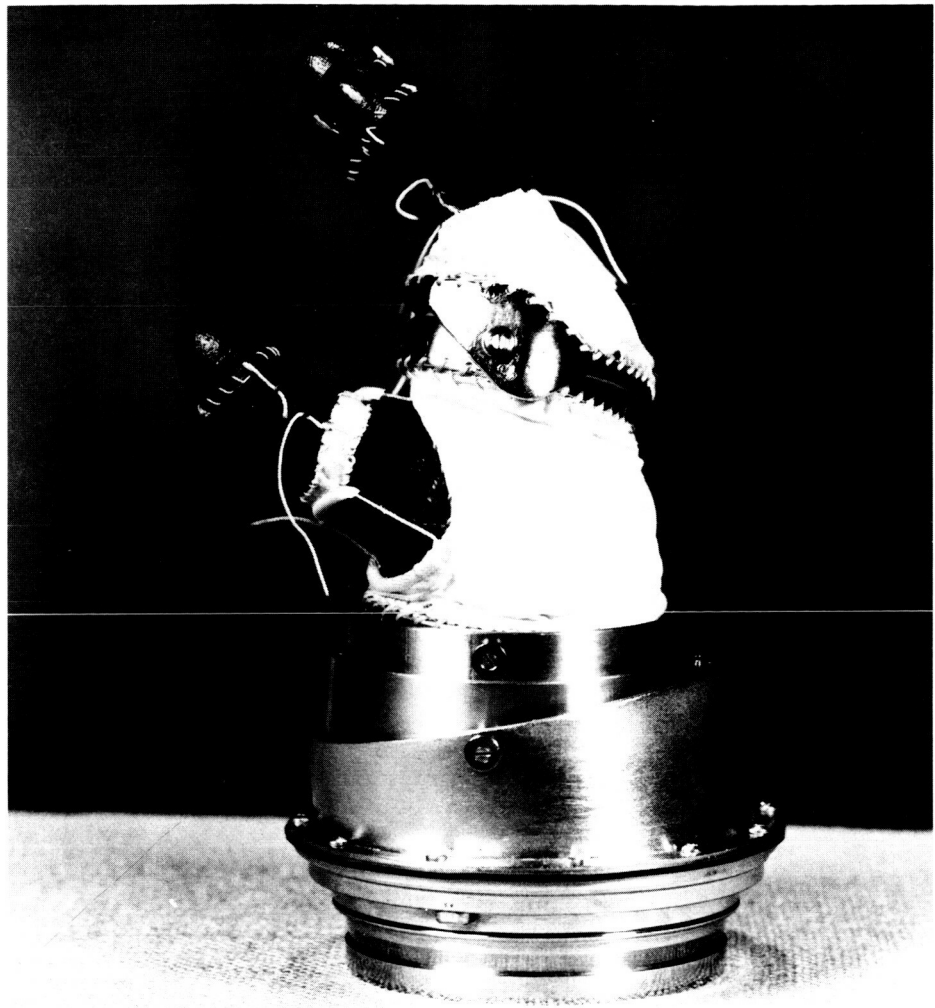
that structural deformations can be measured directly with GPS, and, by using a data link to relay state vector information between two vehicles, GPS can serve as a very accurate tracking aid. The GPS clock can be used as a timebase with an accuracy of 25 nsec. Finally, the system can be used to measure coarse vehicle attitude.

Enhanced Manned Systems

Future manned missions, with larger crew sizes and longer duration activities, will require more efficient manned systems in order to minimize or to eliminate resupply requirements and to improve man's effectiveness.

A comprehensive survey of existing and potential regenerative environmental control and life support system (ECLSS) technology was conducted during the year. The study included both physicochemical and biological concepts and considered the potential commonality between the ECLSS of the Space Station and of future advanced missions such as the manned lunar base. Definition of advanced space missions, identification of unique mission drivers, and development of a tradeoff methodology were also performed.

Increased extravehicular activity (EVA) requirements of Space Shuttle missions and the developing Space Station Program have emphasized the need for improved glove design and performance. These requirements include capability for hand mobility and dexterity functions at suit pressure levels ranging from 4.0 to 8.0 psia, capability to maintain load-bearing capacity (man loads and pressure loads), thermal protection, and abrasion and puncture protection. The key glove performance issue becomes one of finding the right balance between the protection capability and the performance capability of the functional glove. Productivity requires mobility, comfort, ease of donning and doffing, tactility, and safety assurance. Glove design complexity increases with the differential pressure between the glove and the vacuum of space and with EVA task requirements. In order to maintain and improve EVA glove mobility features for high-operating-pressure (8.0 psia) glove assemblies, a series of mobility joint elements is currently under



Internal detail of the 8.0-psi glove.

development. During the year, prototype 8.0-psi glove assemblies have been delivered to JSC for preliminary test and evaluation activities. Follow-on design and development activities for enhancing the various glove mobility features will be planned based on results of the testing activities.

Work continues this year on a variety of standard fixtures for aid in servicing satellites from the Space Shuttle and the manned Space Station. In addition to a joint NASA/Department of Defense (DOD) study effort entitled "Satellite Assembly, Maintenance, and Repair" (SAMS), conceptual designs of several fixtures were initiated. These include a satellite holding device, a force/torque sensing system for the Space Shuttle remote manipulator arm, and a tele-robotic work system (TWS), which consists of a pair of manipulators controlled from the Space Shuttle cabin.

The TWS also shows promise as a "smart" first stage for the orbital maneuvering system being developed as an adjunct to the STS.

Another area of concentrated research has been the generation of communication equipment required for the increased operations when the NASA manned Space Station becomes operational. Infrared crew communications systems have been studied both for crew voice communication and for data transmission, with a special emphasis on providing wireless physiological data from astronauts in the Space Station. Free-space laser transmission has been studied, and emphasis is being placed on improving its applicability for space operations. Another area of great potential is the communication of data optically through the Space Shuttle windows without the need for data cable penetrations.

Manned Presence Above Low Earth Orbit

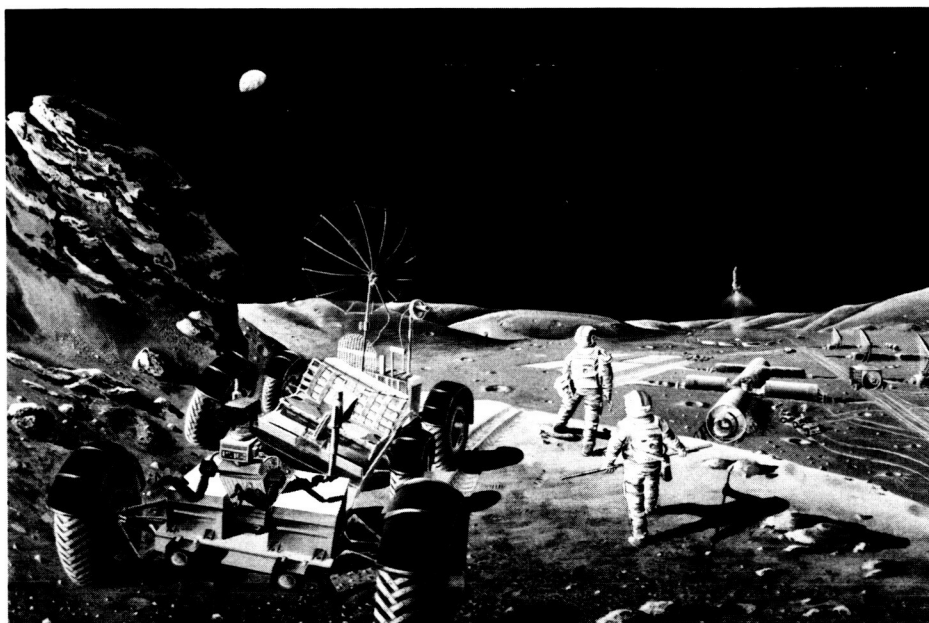
Lunar base concept studies have pointed out the advantages of using lunar resources for the construction and operation of a lunar facility. Students and faculty from Clemson University, working at JSC, constructed equipment for an experiment to demonstrate the production of glass fibers. The experiment successfully produced a larger quantity of glass fibers from an

Apollo 16 simulated soil sample (terrestrial soil with the correct mineral composition) without any preprocessing. The fibers are being tested for their material properties and appear suitable for making fiberglass.

Another study has concentrated on appropriate propellants for supporting a lunar base, including propellants which could be manufactured from lunar resources. The propellants recommended for initial analysis and vehicle performance tradeoff studies

include liquid oxygen, liquid hydrogen, aluminum magnesium, silane, and monomethyl hydrazine. A tradeoff study based on the NASA/JSC-supplied lunar mission transportation model has focused attention on several liquid oxygen/hydrogen and aluminum/oxygen propulsion system concepts. Lunar propellant processing techniques that are applicable to these propulsion systems include hydrogen reduction for oxygen production and acid leaching for aluminum production.

Conceptual lunar base.



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Space Flight Advanced Programs

Significant Tasks

Satellite Services System

TM: Gordon Rysavy/EX2
Reference OSF 1

The fully operational Space Transportation System must meet requirements for a wide range of satellite servicing functions, including capability for payload deployment and retrieval, payload support on sortie missions, and satellite support servicing within, or adjacent to, the Space Shuttle cargo bay. Potential satellite support requirements include: (1) resupply of expendable items such as propellants or raw materials for processing; (2) checkout, maintenance, and repair; (3) reconfiguration of sensors; and (4) component exchange.

Previous studies defined the requirements and provided conceptual designs of various items of satellite services equipment. Some of this equipment is now available or under development, and the remainder consists of newly identified items for future development consideration.

The envisioned servicing equipment will be capable of multiple uses on the Space Shuttle, the Space Station, and orbital maneuvering vehicles and will provide services for satellites of wide-ranging varieties and orbital locations. This commonality will be achieved by maintaining standard interfaces, which are being developed in conjunction with the definition and development of the servicing equipment. Based on customer inputs through study contracts and workshops, concepts are defined and given testbed evaluations leading to flight hardware specifications.

The NASA goals are to baseline generic servicing equipment and to standardize the servicing interfaces, thus allowing satellite developers to consider servicing in their original design phase.

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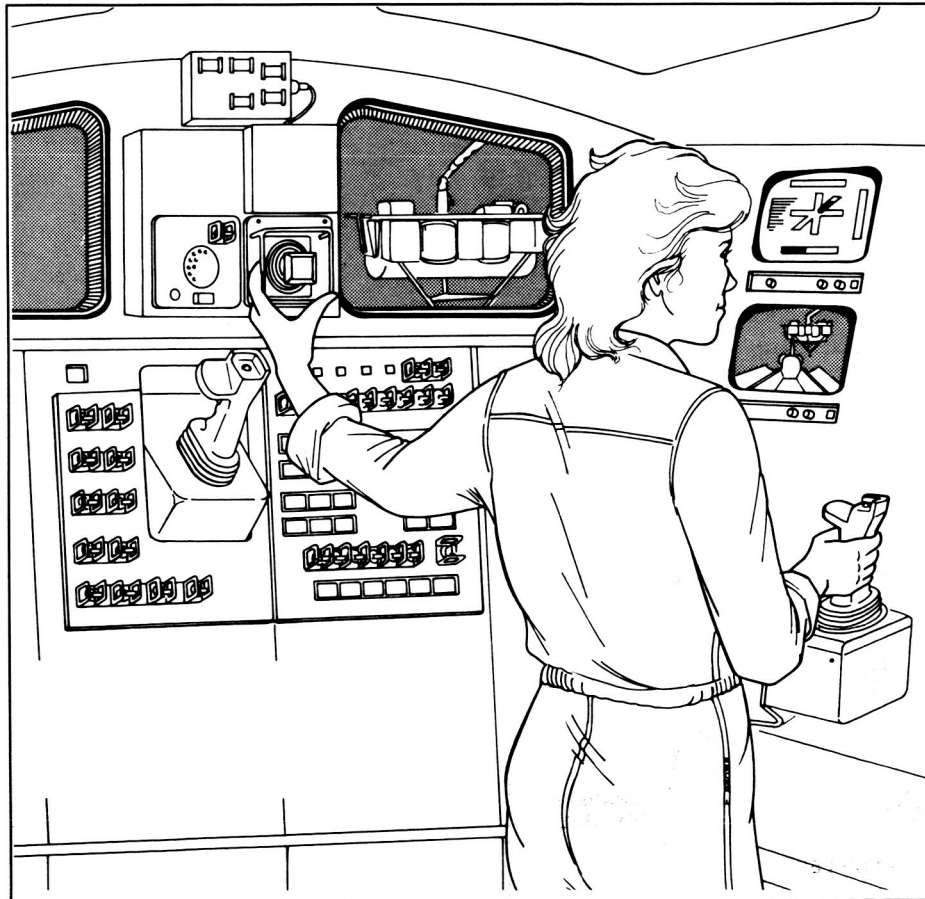
Major activities initiated and conducted in 1986 include the conceptual design of a versatile, lightweight satellite holding device, development of a force/torque sensing (FTS) system for the remote manipulator system (RMS), telerobotic work system concept development (see OSF 2 for details), and a joint NASA/Department of Defense (DOD) study program called Satellite Assembly, Maintenance, and Servicing (SAMS).

The satellite holding device will be used for the maintenance, repair, checkout, and temporary berthing of satellites during on-orbit operations. It will include provisions for fluid, power, and avionics interfaces. The satellite holding device is stowed within the Orbiter cargo bay and is deployed over the longeron for use. Its berthing interface with the satellite is compatible with the previous serviceable satellites developed by the Goddard Space Flight Center, to maintain commonality.

The FTS system is currently being developed for the Orbiter RMS. This system will consist of a force/torque sensor on the RMS, a computer and video graphics generator on the Orbiter aft flight deck, an interconnection with the closed circuit television monitors and recorders, and a graphics retrieval and information display (GRID) compass computer keyboard interface. The hardware is presently being manufactured to class D payload guidelines and will be used as an operational prototype in helping to manipulate noncritical payloads and in assisting in the performance of other RMS tasks.

The SAMS study effort will consider DOD, NASA, and commercial spacecraft and will cover all aspects of on-orbit servicing, including requirements, spacecraft design, hardware/tools, mission scenarios, and system analysis. The culmination of this first-phase study will lead to the identification of selected hardware and procedural proof-of-concept evaluations to be conducted in the second phase of the SAMS program.

FTS system enhancing RMS capabilities.



Telerobotic Work System Definition Study

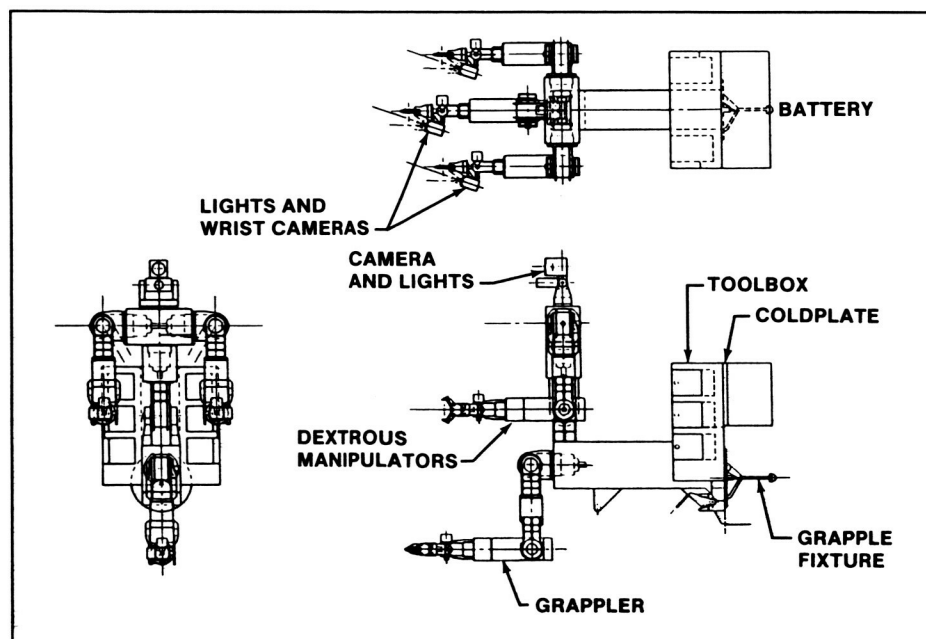
TM: Lyle M. Jenkins/EX2
Reference OSF 2

The requirements for servicing, assembling, and maintaining space systems have created the need to provide supplements and alternatives to extra-vehicular activity (EVA) by crews of the Space Shuttle and the Space Station. Remote operating systems that increase the capability and productivity of the space crew can effectively meet the need. Systems using automation and robotics technology to perform tasks in time-critical and hazardous situations are new tools to be developed for the Space Transportation System capability.

An EVA by the astronauts has been demonstrated as an effective and versatile means of working on satellites and of building structures in space. Remote operating systems with a capability equivalent to the astronaut in an extra-vehicular mobility unit (EMU) offer an increase in productivity and retain operational redundancy by keeping tasks compatible with backup by the EMU-equipped astronaut. The increase in crew productivity for a remote operating system can be augmented by technology evolution from teleoperation to telepresence to supervisory control of a monitored robotic mode. Sensors feed data on conditions at the work site to the operator's displays as well as to the computer. The operator and the computer work together in controlling dexterous manipulators to accomplish intricate tasks that presently can be done only by an EVA astronaut. The implementation of this approach is being studied in the concept of a telerobotic work system (TWS).

The TWS is a concept that applies teleoperations, telepresence, and robotic technology to space operations. The TWS concept is being developed in system definition studies by Grumman Aerospace Corporation and Martin Marietta Aerospace. The concepts defined are anthropomorphic in configuration with two dexterous arms approximately the length of human arms. Television cameras transmit views of the work site to the operator located in the Space Shuttle Orbiter cabin or in a Space Station module. Initial results of the studies have formed the basis for consideration of a similar system for the Space Station. Grumman performed laboratory simulations of Space Station structure assembly using dual manipulators in master-slave and six-degree-of-freedom rate control modes. Martin Marietta is developing control station concepts compatible with the Orbiter cabin constraints. Early flight experiments will be needed to resolve the effect of zero g on the system, control, and tasks.

Work station equipment.



Rendezvous/Proximity Operations Guidance, Navigation, and Control System Study

TM: William L. Jackson/EH24
Reference OSF 3

The requirements for interactive space traffic control will be increasing as new vehicles (manned and unmanned) and capabilities are developed for the space fleet. Automated systems to support these requirements must be developed and used to maximize fleet productivity. The design of automated systems is greatly enhanced by developing tools and local work stations that the design engineer can use for performing parametric analyses on an evolving design. The automated rendezvous and proximity operations simulation has been developed in response to that need.

A reference nonmaneuvering particle (Space Station or Orbiter) and as many as five maneuvering free-flyers can be defined. An important design feature of the simulation is an asynchronous task executive, which propagates all platforms to the time of the next scheduled event and allows the user to define and execute new applications or subsystem algorithms without modifying the program structure.

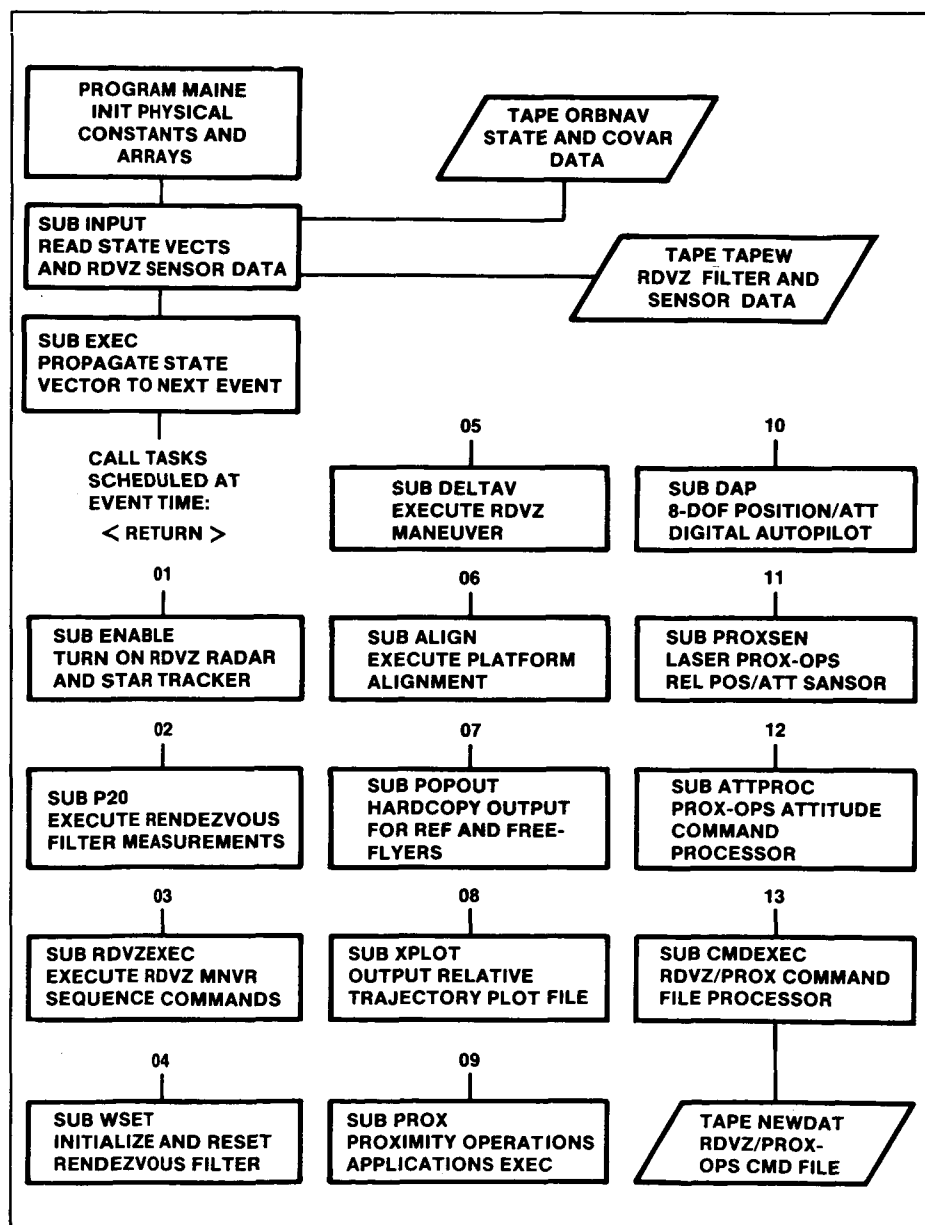
The simulation provides generic subsystem models for rendezvous navigation sensors, the inertial subsystem, and the global positioning system. A maneuver command file executive, together with a newly developed algorithm for maneuver computations, allows arbitrary sequences of maneuvers to be specified and executed. Maneuver computations account for the effects of finite thrust and all modelled disturbing accelerations.

In the proximity operations mode, the simulation switches to six-degree-of-freedom (DOF) equations of state for each free-flyer and activates the proximity operations applications executive. This task interfaces with the command file executive to implement a user-specified suite of proximity operations activities including position hold, soft dock approach, transfer, etc. The proximity operations applications task provides subroutine templates for implementing new types of commands and activities, and it standardizes the interface with the six-DOF autopilot,

which controls attitude and translation. A feature of the command file executive permits halt points to be defined by the user, so that new commands may be entered during the course of the run. The proximity mode offers a variety of attitude control regimes, a model of a relative position/attitude determination sensor, and the capability to account propellant expenditure by axis and function (attitude or translation).

In general, the simulation models first-order error sources and environmental effects to the level necessary to make credible judgments about operational feasibility, subsystem performance requirements, and consumable stores. The simulation is coded in ANSI Fortran 77, and can execute on any compatible machine, including IBM PC's, VAX, and CYBER.

Automated rendezvous and proximity operations simulator program elements and architecture.



Interactive Graphics Control System Design

TM: E. T. Kubiak/EH2
Reference OSF 4

Recent advances in the technologies of microcomputers and high-speed graphics allow a truly interactive approach to the solution of complex guidance, navigation, and control (GN&C) analysis problems. As a computationally intensive program is being executed on a host microcomputer, the analyst can be simultaneously viewing the output data in a variety of formats (e.g., two-dimensional (2-D), 3-D, etc.) and can make appropriate midrun changes. This solution approach is a boon to complex analysis problems in that it benefits both analysis efficiency and, because it typically improves insight, analysis quality.

In fiscal year (FY) 1986, the promise of this interactive technology was illustrated by several significant analysis applications. These applications involved tethered satellite dynamics, control moment gyro (CMG) momentum management, and optimal jet selection theory.

To support studies of tether dynamics, high-speed graphics were used to depict the relative motion of multiple tethered objects connected by either massless or "bead" element tethers. The motion could be observed in any plane or choice of planes, as shown in the accompanying figure, or even in 3-D by isometric viewing. Using this capability, the analyst could readily (1) differentiate between tumbling and normal tether librations, (2) identify subtle errors in run construction (initial conditions), (3) visualize instabilities in release/reel-in dynamics, and (4) characterize the potential for recontact in various failure scenarios.

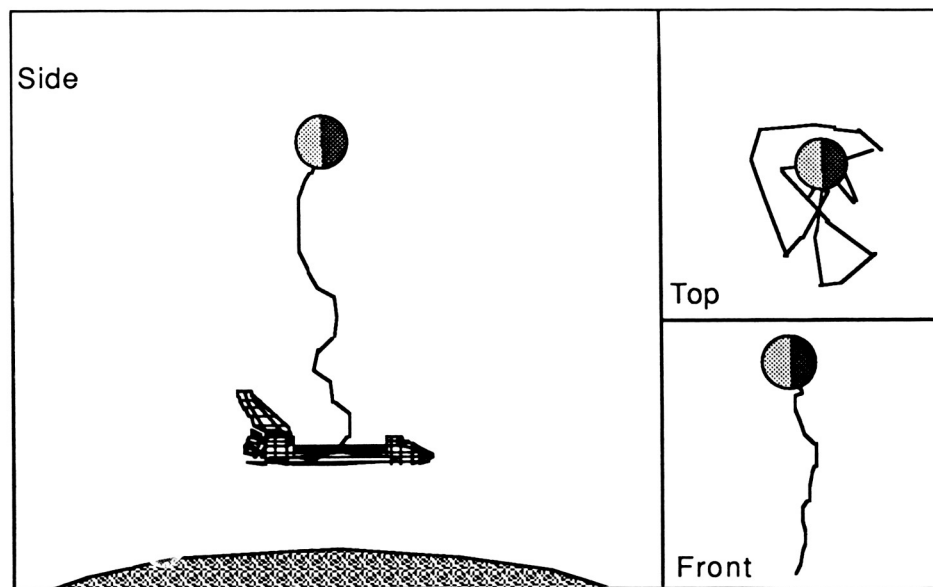
Comprehension of CMG steering and of momentum management control laws was promoted by the design of a 3-D representation which showed the time varying the relative motion of momentum vectors of the individual CMG's. During data playback, the analyst could manually adjust the viewing eyepoint to obtain the best perspective of the rotating vectors. Therefore, for various spacecraft maneuvers, the analyst could quickly grasp how well individual control law objectives were met and how close the CMG's were to saturation (co-alignment).

Finally, an application was made of optimal jet logic theory which provides substantial heuristic insight into an otherwise mathematically complex problem. The basic problem statement is as follows: Given a desired rate change in a state vector, determine the selection of thrusters and corresponding thruster on-times which produce the desired rate change with a minimum net on-time. A two-part mathematical derivation had been made. First, for any given rate change, it defined which thruster combinations could be optimal (correspondingly, some combinations are never optimal). Second, given a specific rate change request, it showed how to choose the particular combination which is optimum. Although this mathematical concept applies to general n -degree-of-freedom (DOF) formulations, a typical application would be to three-DOF spacecraft rotational control, and for this case graphical visualization was of immense benefit. It can be shown for the sets of optimal thrusters that the end points of the thruster acceleration vectors define planar surfaces with faces (triangular surfaces) corresponding to the optimality boundaries. If a surface is penetrated by the desired rate change vector (or its extension), then the set of thrusters which

define the surface vertices are the optimal set of thrusters. Since the planar surfaces define an overall "closed" surface (convex polytope), there will in general be only one intersection or one set of optimal thrusters. This application has spawned insights into controllability criteria which are currently being developed.

Although past accomplishments more than justify the concept of interactive control system design, a key task objective still remains. This objective is to perform midrun interactive control system design for a problem involving complex dynamics. The availability of the high-speed microcomputer will complete the required environment to meet this most demanding objective. Simulation and analysis programs are currently being hosted that will provide design capability for the complex on-orbit problems of optimal control in rendezvous and proximity operations. A key goal for FY 1987 is to converge on the remaining objective by using these analysis tools in the interactive environment to perform fundamental control system synthesis.

Tether control dynamics.



Data and Software Systems Commonality

TM: Robert G. Musgrove/EH6
Reference OSF 5

The advent of long-duration, manned space flight programs, literally spanning generations, requires that considerable attention be paid to designing systems that can be replaced, maintained, shared (or reused), and upgraded with minimum impact to the mission. Nowhere is it more important to carry forward this philosophy than in the development of the spaceborne computing systems.

Reuse and maintainability of software and hardware systems for long-life-cycle systems have resulted in the emergence of the term "commonality," which, for large-scale, evolving flight systems, can be reduced to a simple definition of the attribute of planned sharing of system resources where the resources are defined as hardware, software, facilities, tools, etc.

The Data and Software Systems Commonality Research and Technology Objective and Plan (RTOP) has as its ultimate goal the development of guidelines and groundrules which could be implemented as agency policy with the objective of promoting commonality across flight programs. For some time, commonality initiatives had been under way on a local basis within each of the NASA Programs or Centers, but it had not yet drawn an agency focus. As a means of providing this focus, activity for the fiscal reporting year 1986 was divided into two major components. First, a comprehensive survey was conducted by Center and by Program to determine commonality initiatives and to identify who was performing the work. In June, this work culminated in a two-day roundtable session held at the Johnson Space Center (JSC) with representatives from NASA Headquarters, NASA field centers, the Department of Defense, industry, and academia to report briefly the status of commonality initiatives and to determine ways of directing attention to commonality on a NASA-wide basis. The consensus of the roundtable session was that commonality should definitely become a major agency concern and that conducting a workshop would be a good means of providing the proper focus. The participants then assisted in defining the initial strategies for topical content and key workshop participants.

From June to October, activity concentrated on defining detailed thematic content, on structuring the agenda to provide an adequate balance of views, on securing presenters and panelists, and on finalizing the considerable logistics of publicizing, organizing, and staging the 3-day conference entitled "Workshop on Commonality in Computing for NASA Flight Systems." Because commonality is still perceived by many as an abstraction, its interpretation can have many facets, and it is difficult to quantify accurately the benefits in terms of a well-understood econometric model. The problem is further compounded because most major flight projects have figured separately the costs to implement and the costs to maintain. Therefore, a key goal of the workshop was the attempt to make the first step toward translating commonality from an abstract concept into candidate implementations or policy scenarios.

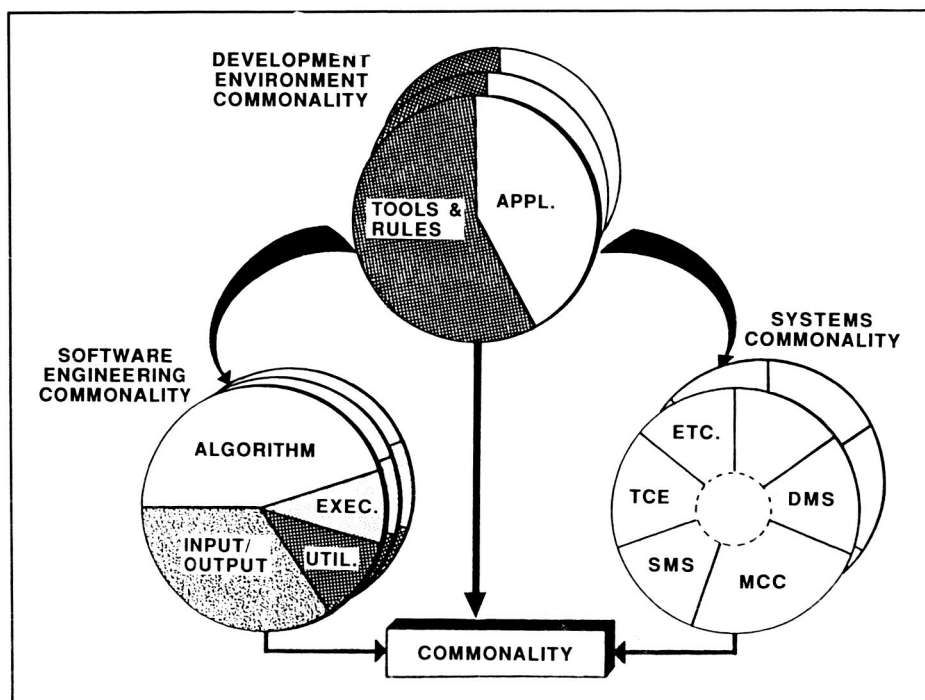
Nearly 400 people attended the workshop on commonality, which brought together representatives from government, industry, and academia to share views and experiences regarding commonality. The workshop was structured to address why commonality is needed, how standards might apply to commonality, what management issues are associated with commonality, and what lessons have been learned by those

with experience. As would be expected of this kind of forum, especially the first one that NASA has dedicated to address commonality specifically, more issues than recommendations surfaced. However, along with the issues came some good advice from those who have experienced the time when commonality was not a consideration and from those who are concerned about the future if it does not become one.

The individual papers and a summary of the panel discussions will be compiled for publication to be released in early calendar year 1987. Beyond these proceedings, however, JSC intends to synthesize the issues, to develop and to prioritize suggested scenarios for addressing those issues, and to brief these to NASA Headquarters as possible implementation approaches across programs.

A key message of the commonality workshop was best expressed by a workshop panelist who defined commonality as a state of mind or being. It must be embraced as an objective, but rewards and incentives must be clear before it will gain acceptance. For a product to achieve commonality and widespread acceptance, it must have (1) the capability to fulfill a need, (2) transportability (commonality) as a stated goal, and (3) management committed to it.

Data and software systems commonality relationships.



Orbital Transfer Vehicle Guidance, Navigation, and Control System Technology

TM: Gene McSwain/EH2
Reference OSF 6

The next generation of space vehicles will include space-based reusable orbital transfer vehicles (OTV's) that employ aerobraking to return to low Earth orbit. Aerobraking reduces the operational costs of an OTV by reducing the amount of propellant that must be delivered by the Space Shuttle to low Earth orbit. The focus of this study, as outlined in the following description, is the development of the guidance, navigation, and control technology required to perform aerobraking returns to the Space Station routinely.

The lift-to-drag ratio (L/D) for an operational lifting-brake OTV will be a critical factor in the vehicle configuration and basic design. A high L/D , on the order of 0.3, is preferable from a guidance standpoint since it provides more trajectory control authority during the critical phases of aeroassist. Unfortunately, a high L/D presents problems in terms of vehicle packaging (center of gravity location, aerobreak shape) and thermal protection because of a high angle of attack. Protection of payloads from flowfield impingement is also more difficult at large angles of attack. For these reasons, it is important that the guidance L/D requirements be identified. A requirements budget that identifies the impact of error and dispersion sources on the required L/D has been developed. These sources include atmospheric variations (density bias, shear, etc.), navigation errors, entry trajectory perturbations (primarily flightpath angle), roll reversal rates and accelerations, and uncertainties in vehicle aerodynamic properties.

An operational global positioning system (GPS) will provide spacecraft such as OTV's with the opportunity for very precise autonomous navigation. For differential velocity (ΔV) maneuvers (either thrusting or aerobraking), an inertial measurement unit (IMU) will continue to be required as an attitude reference and as a navigation support during translational maneuvers. Highly accurate inertial systems that are capable of operating for an extended period without an external update to support IMU alignment may not be required in the GPS

era. This reduced requirement should lower costs and add to the list of potential IMU candidates.

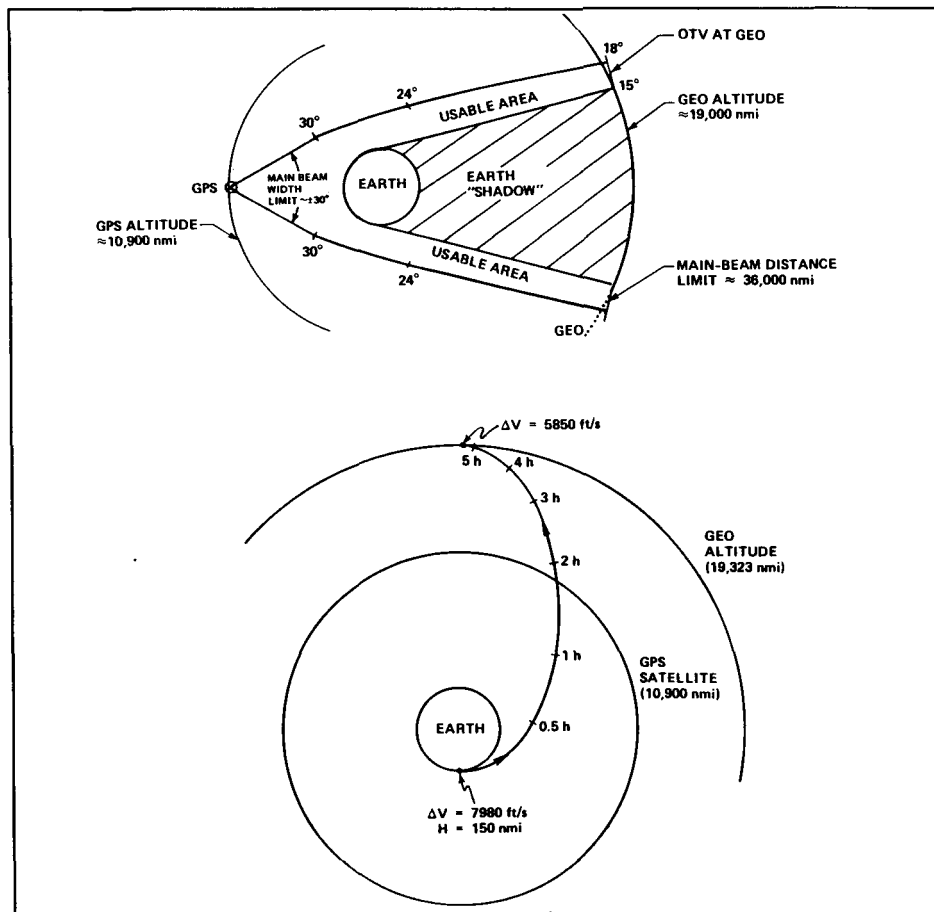
The primary objective of this study task is to determine whether the use of GPS and a tracking and data relay satellite (TDRS) will permit a relaxation of the performance requirements for other navigation aids. If GPS and/or TDRS can effectively update the IMU alignment error estimates, then less frequent stellar updates will be required. If sufficient coverage is provided by GPS and/or TDRS during key mission phases, and if the measurement geometry is effective, then the accuracy requirements on the IMU may be relaxed and the cost may be reduced.

As part of this study, a linear covariance simulation has been developed to study navigation system performance on typical OTV mission phases. The initial studies will use an inertial navigation system (INS) with performance characteristics comparable to those of the Honeywell linear INS. In subsequent studies, the IMU performance characteristics will be degraded and stellar

update frequency will be reduced to determine the sensitivity of the navigation performance.

Current spacecraft (particularly manned systems) require redundancy in the navigation system components. The Space Shuttle Orbiters with three gimballled IMU's and the inertial upper stage which uses a five-gyro strapdown package are good examples of these spacecraft. Fault detection for soft failure conditions typically involves some sort of voting or midvalue selection logic to isolate a faulty component or system. This method often involves extra redundancy to break a tie between two measurements. Consideration has been given to using the GPS radio navigation to aid the fault detection and isolation process (and perhaps determine the best performing components in the overall system). Future studies will evaluate the use of two or three low-cost strapdown inertial systems as a means of providing reliable, fault-tolerant navigation.

GPS-aided navigation for low Earth orbit (LEO) to geosynchronous Earth orbit (GEO) transfer.



Advanced Space Flight Simulation Technology

TM: Kathleen J. Healey/EF
Reference OSF 7

An analysis of advanced program requirements in the area of expert systems identified several high-potential areas for further investigations. These areas, in priority order, are (1) expert systems that operate in a real-time dynamic environment and interface with flightcrew and/or flight subsystems; (2) expert systems that facilitate the development, operation, and configuration management of real-time simulations supporting advanced programs; and (3) automated flight system design tools.

Four prototype expert systems were developed, and one has been selected for further enhancement and integration in an appropriate environment. The prototypes developed were (1) a simulation-aided design tool for distributed control of large space structures, (2) a simulation configuration expert system, (3) an intelligent end effector expert system, and (4) a rendezvous expert system.

The simulation-aided design tool for distributed control of large space structures allows for rapid prototyping of symbolic candidate designs of distributed controllers for attitude and translation of large-scale, flexible structures. It has proven to be a powerful and easy-to-use tool. The second item, the simulation configuration expert system, determines optimum configurations for the software of a large simulation facility. An optimum configuration is defined as an allocation of software routines to processors that satisfies routine frequency requirements and data dependencies and that minimizes the duty cycle of the implementation. The third item, the intelligent end effector expert system, is a collection of expert systems for scheduling and controlling a simulated dual arm end effector on line. The expert system includes an automatic task interpreter and a trajectory planner. The rendezvous expert system is a real-time rendezvous procedures generator designed to assist the Space Shuttle flightcrew during a rendezvous of the Space Shuttle with a target such as the Space Station.

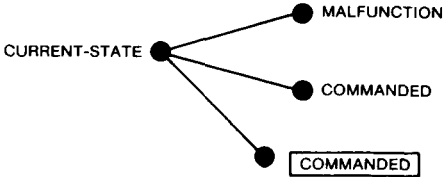
The rendezvous expert system has been selected for further development and integration because it addresses the area identified as having the highest potential for advanced programs and because it takes full advantage of a major real-time engineering simulation facility that is available to the researchers and that provides an excellent environment for integration. This facility is the Systems Engineering Simulation (SES) Laboratory, which is located at the Johnson Space Center and is used extensively for real-time engineering evaluation of advanced concepts and for on-orbit procedures development and flightcrew familiarization.

Rendezvous between the Space Shuttle and a target is a highly demanding, crew intensive maneuver involving multiple Space Shuttle subsystems. When subsystem failures occur, a rendezvous maneuver in progress is often aborted. The rendezvous expert system is designed to assist the crew, to alleviate their workload under both nominal and off-nominal conditions, and, in many cases, to generate successful procedures for rendezvous completion under conditions which would currently result in a rendezvous abort.

The prototype rendezvous expert system currently addresses selected portions of a rendezvous maneuver and is integrated with a custom-built simulation of the Space Shuttle, its subsystems, and the Space Station. The expert system interfaces with the flightcrew via a display, which is illustrated in the figure. Information available to the crew includes advisories that certain subsystems are operating in suboptimal modes, descriptions of the current and possible next states of the subsystems, advice on the optimum next states for subsystems requiring state transitions, and explanations for the expert system's selection of the optimum next states.

The rendezvous expert system will be enhanced and modified for integration with the SES and the SES's Space Shuttle aft cockpit. Completion of this project will enable engineering evaluations, procedures development, and crew familiarization with a real-time expert system integrated in an appropriate and realistic environment.

Information as displayed by the rendezvous expert system.

ORBITER SUBSYSTEMS STATUS			
DIGITAL AUTO PILOT			
MODE	SUB-OPTIMAL		
FUEL	LOW		
CONTROL			
ATTITUDE	NO ERROR		
SENSORS	COAS-SUBOPTIMAL		

EXPLANATION			
DAP CONFIG SETTINGS: (HIGH PRECISION) GAIN LOW RATE-LIMIT LOW DEADBAND LOW (HIGHER-POWERED JETS) MODE NORMAL A SUBOPTIMAL STATE:		CHANGE DAP CONFIG SETTINGS: GAIN FROM LOW TO HIGH RATE-LIMIT FROM LOW TO HIGH DEADBAND FROM LOW TO HIGH WILL GAIN: FUEL-EFFICIENCY WHILE SACRIFICING: PRECISION	
CURRENT STATE		POSSIBLE NON-TIMEOUT TRANSITION	
		POSSIBLE NEXT STATE	

DAP CONFIG SETTINGS: (LOW PRECISION) GAIN HIGH RATE-LIMIT HIGH DEADBAND HIGH (HIGHER-POWERED JETS) MODE NORMAL THE OPTIMAL STATE:	
POSSIBLE NEXT STATE	

Space-Shuttle-Derived High-Altitude Atmospheric Density Model

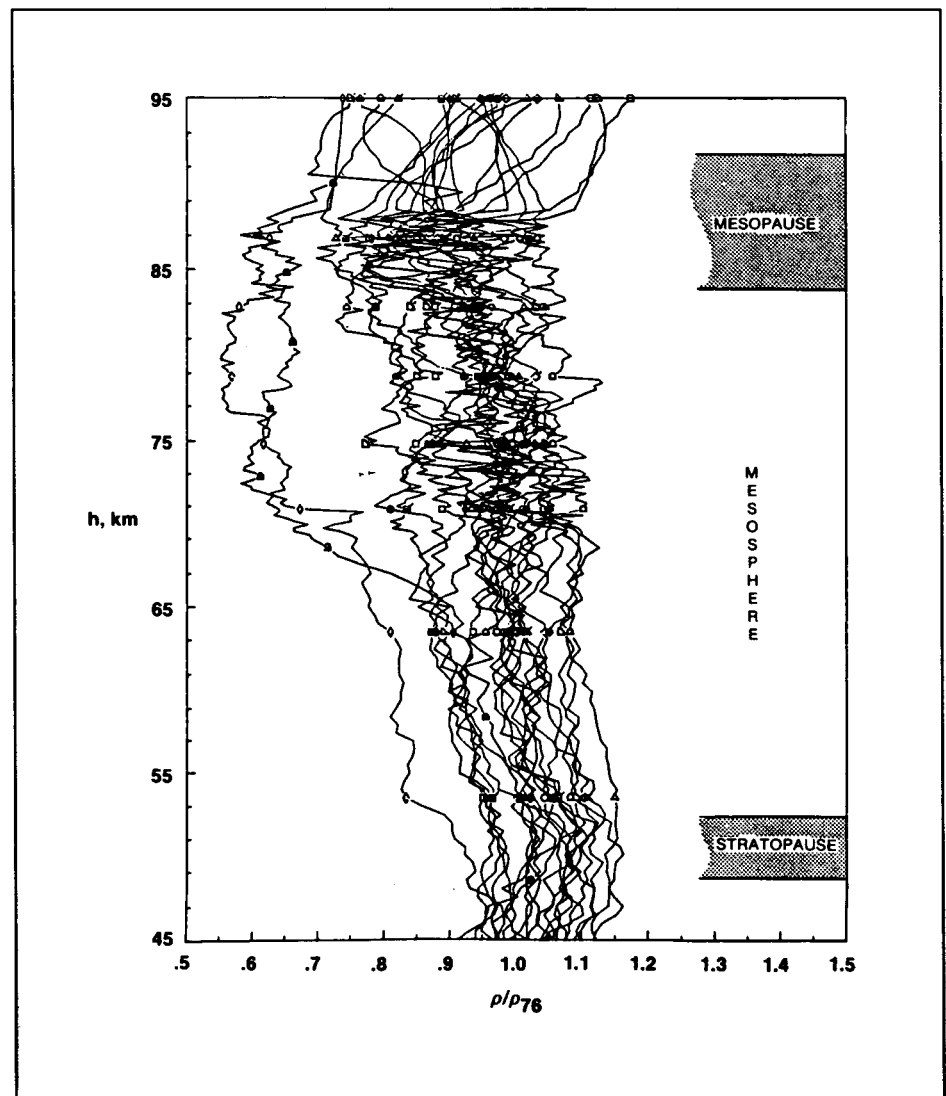
TM: Joe D. Gamble/ED3
Reference OSF 8

Flight data from the early Space Shuttle entries indicated significant gradients in the atmospheric density profiles in the mesosphere region (approximately 50 to 90 km). Changes in density of 15% to 20% occurring over altitude increments of less than 1 km were observed on Space Transportation System (STS) mission STS-4. Since advanced entry vehicles such as the aeroassisted orbital transfer vehicle (AOTV) will be using this altitude region for much of their maneuvering, accurate models of the atmospheric density are required. Early design studies of the AOTV have shown a particular sensitivity of the guidance performance to large density gradients occurring over a small altitude variation. It has been difficult in the past to obtain accurate measurements of density changes over small altitude increments near the upper bounds of the mesosphere. Since the Space Shuttle provides continuous accelerometer measurements during its descent, it represents an ideal test vehicle for obtaining high-resolution density measurements.

An activity has been established for obtaining sufficient high-altitude density measurements from the Space Shuttle entries to build a statistical data base that can be used to improve atmosphere models in the mesosphere region. Accelerometer measurements from the Orbiter inertial measurement unit and aerodynamic coefficient identification package are used to derive the atmospheric density along the entry trajectory. These data are compared and correlated to density models of various existing atmosphere models and to the model derived from a best estimated trajectory reconstruction of the entry trajectory. These analyses are being used to help define density dispersions for application in the preliminary design of advanced vehicles such as the AOTV.

A data base has been compiled from the first 22 Space Shuttle entry flights and will be available for use on IBM-compatible personal computers. Comparison of these data to existing atmosphere models indicates that the Marshall Space Flight Center's global reference atmosphere model produces density perturbations similar to those observed on the Space Shuttle entries when the random perturbation option is used. As additional Space Shuttle data are acquired, a statistical model including seasonal and limited latitudinal effects will be constructed and used to evaluate existing atmosphere models further.

Ratio of Space-Shuttle-derived density profiles to U.S. 1976 standard atmosphere for 22 Space Shuttle flights.



Lunar Base Missions and Opportunities

TM: Barney B. Roberts/ED13
Reference OSF 9

The Johnson Space Center (JSC) is responsible for the definition of future lunar bases. This definition includes the missions (i.e., those surface elements or activities that produce valuable products, including scientific knowledge), the surface systems that support and enable the missions, and the required supporting transportation systems. Thus, to be able to define effectively a lunar base and its associated surface and space support infrastructure, it is necessary first to generate a data base of all conceivable missions. In this context, a mission is a single or multipurpose objective that has some definite end product and that can be segregated in some way, usually by a piece of hardware that is unique to the objective or required for support of the objective. Recent studies sponsored by JSC have begun to assemble such a data base. These studies have resulted in the systematic definition, appraisal, and documentation of future civilian space missions. In particular, efforts have focused on defining a complex data base of specific missions in terms of objectives, infrastructure demands,

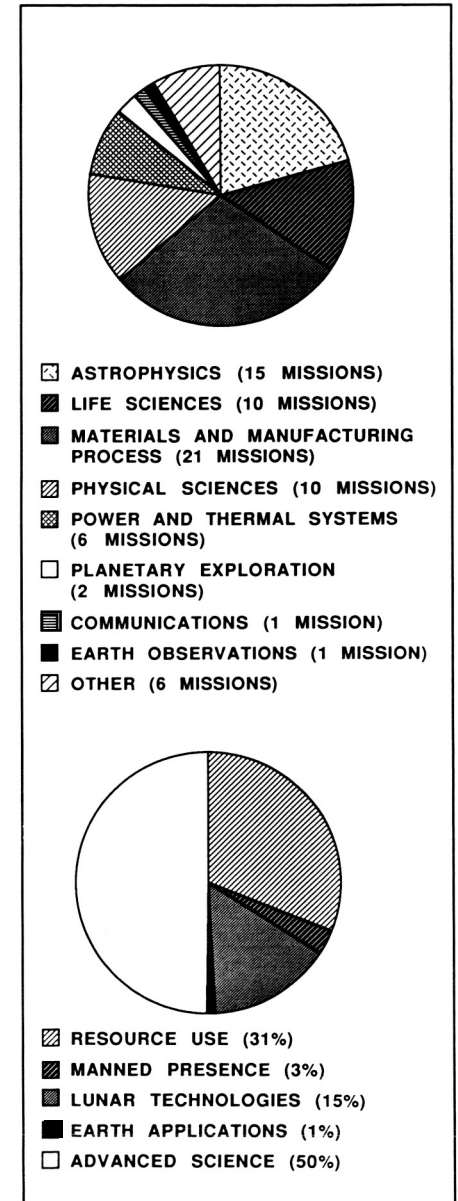
and technology needs. With the mission set, it is possible (1) to develop a broad range of scenarios for the future civilian space programs that emphasize a singular or multifaceted set of goals and (2) to determine infrastructure requirements and associated impacts.

The lunar base mission data base permits record of and access to data regarding currently planned missions and future opportunities at the Moon. At the present time, 72 missions are in the mission data base. These missions are not a complete listing of all possible advanced space activities; however, they are representative of currently planned activities and the view of what the future might bring, based on inquiries with interested members of the scientific community. Each mission includes the following qualitative and quantitative information: (1) brief description of the mission; (2) mission objective and rationale; (3) benefits and goals; (4) specific mission data, including mass and volume of equipment, desired orbit or location, and estimated start date and duration; (5) data and communication requirements; (6) operational and servicing requirements; (7) technology development status; and (8) cost (mission costs currently are not available).

The missions in the data base can be divided into five basic types of missions: those that (1) utilize lunar resources, (2) advance the scientific knowledge base, (3) benefit man on Earth, (4) develop and demonstrate technologies to support the space infrastructure, and (5) extend man's presence in space.

Future activities will be to develop these mission elements and to assemble them into ordered sets that reflect a particular advocacy or collection of advocacies.

Lunar base mission resource allocation.



A possible martian exploration effort with base elements such as greenhouses, habitat and laboratory modules, and transverse vehicles.



Laser/Optical/Infrared Communication System

TM: James C. Lamoreux/EE6
Reference OSF 10

Several communications requirements for the Space Shuttle and Space Station programs can best be satisfied with optical techniques. The data transfer requirements between the crew cabin and the payload bay change as the missions and payloads change. Some payloads need special accommodations requiring additional cable penetration through the cabin/payload bay interface. Quantitative physiologic data from crewmembers is required during specified activities. The implementation of the collection and communication of these data to a computer and/or recorder should not interfere with the activities of the crewmember. Furthermore, secure, reliable, short-range communication links with a high data rate are required for proximity operations and for robotic applications in both the Space Station and the Space Shuttle Programs. The objective of this task is to develop systems based on laser and electro-optic technology that will satisfy the unique communication requirements and will enhance NASA missions and capabilities planned for the next decade.

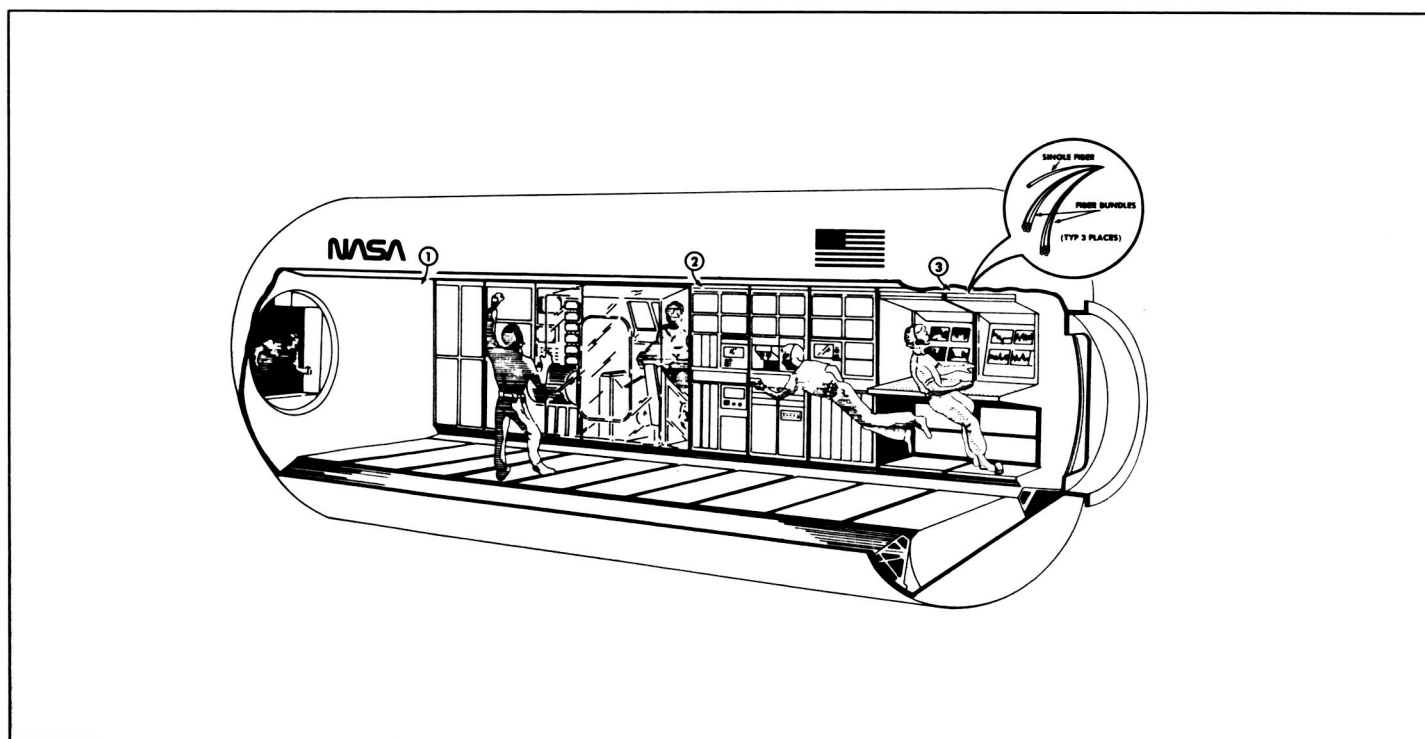
The efforts in this project are concentrated on developing configurations, techniques, hardware, and flight experiments to provide such capabilities as wireless infrared (IR) physiological data links; multichannel, wireless IR crew communications; free-space laser communication links for transmitting voice, commands, and data for manned and robotic proximity operations and for attached or detached payload operations; microwave and/or high-data-rate transmission over fiber optics; and optical communication through spacecraft windows or across rotating interfaces.

Substantial progress has been made in several of these areas. A two-channel simplex IR physiological data link system has been completed and demonstrated, and multichannel systems for simplex physiological data and duplex voice transmission are now being designed and developed. These advanced designs may use fiber optics as passive transmitters and receivers and will allow crewmembers to move from module to module without losing communications or having to reconfigure the communication link.

A free-space duplex laser communications link has been established and is being tested and evaluated. Future efforts will concentrate on improving performance and adaptability to space applications.

Techniques for transmitting high-rate data through an aft Space Shuttle window have been breadboarded, using fiber optics and self-focusing lenses, and candidate fiber optic cables and connectors are being tested in a thermal-vacuum space environment.

Infrared communications using a multichannel system.



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	Office of Space Sciences and Applications
	Life Sciences
OSSA 1	Considerations in the Design of a Health Maintenance Facility for the Space Station Funded by: Life Sciences (UPN-199) Technical Monitor: James S. Logan/SD2 Principal Investigator: Mary M. Jurmain/SD2 Task Performed by: Technology Incorporated Contract NAS 9-17200 Lyndon B. Johnson Space Center
OSSA 2	Treatment Capabilities for Space Station Health Maintenance Facility Funded by: Life Sciences (UPN-199) Technical Monitor: James S. Logan/SD2 Principal Investigator: Michael F. Stolle/SD2 Task Performed by: Technology Incorporated Contract NAS 9-17200 Lyndon B. Johnson Space Center
OSSA 3	Computerized Medical Decision Support for the Space Station Health Maintenance Facility Funded by: Life Sciences (UPN-199) Technical Monitor: James S. Logan/SD2 Principal Investigator: David V. Ostler/SD2 Task Performed by: Technology Incorporated Contract NAS 9-17200 Lyndon B. Johnson Space Center
OSSA 4	Mechanical Ventilation for Medical Patients Aboard the Space Station Funded by: Life Sciences (UPN-199) Technical Monitor: James S. Logan/SD2 Principal Investigators: Bruce A. McKinley/SD2 and Dwayne R. Westenskow Task Performed by: Technology Incorporated Contract NAS9-17200 University of Utah Contract NAS 9-17345 Lyndon B. Johnson Space Center
OSSA 5	Dynamics of Whole-Body Nitrogen Washout While Breathing 100% Oxygen Funded by: Life Sciences (UPN-199) Technical Monitors: David H. Horrigan, Jr./SD5 and James M. Waligora/SD5 Principal Investigators: John H. Gilbert III/SD5 and Benjamin F. Edwards, Jr./SD5 Task Performed by: Technology Incorporated Contract NAS 9-17200 Lyndon B. Johnson Space Center
OSSA 6	Clinical Laboratory Capability for the Health Maintenance Facility Funded by: Life Sciences (UPN-199) Technical Monitor: Bernard J. Mieszkuc/SD4 Principal Investigator: Karen Gaiser/SD4 Task Performed by: Northrop Services, Inc. Contract NAS 9-15425 Lyndon B. Johnson Space Center
OSSA 7	Processing Kit for Microvolume Blood Samples Funded by: Life Sciences (UPN-199) Technical Monitor: Philip C. Johnson/SD Principal Investigators: Theda Driscoll/SD4 and Ron Nachtman/SD4 Task Performed by: Northrop Services, Inc. Contract NAS 9-15425

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	Solar System Exploration
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OAST 2	Thermal Management for On-Orbit Energy Systems Funded by: Space Research and Technology Base (UPN-506) Technical Monitor: J. G. Rankin/EC2 Task Performed by: Grumman Aerospace Corporation Contract NAS 9-16781
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1. Report No. NASA TM-58277		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle Research and Technology 1986 Annual Report of the Lyndon B. Johnson Space Center				5. Report Date December 1986	
				6. Performing Organization Code	
7. Author(s)				8. Performing Organization Report No. S-557	
				10. Work Unit No. 569-85-00-00-72	
9. Performing Organization Name and Address Lyndon B. Johnson Space Center Houston, Texas 77058				11. Contract or Grant No.	
				13. Type of Report and Period Covered Technical Memorandum	
12. Sponsoring Agency and Address National Aeronautics and Space Administration Washington, D.C. 20546				14. Sponsoring Agency Code	
15. Supplementary Notes					
16. Abstract <p>Johnson Space Center accomplishments in new and advanced concepts during 1986 are highlighted. Included are research funded by the Office of Aeronautics and Space Technology; Solar System Exploration and Life Sciences research funded by the Office of Space Sciences and Applications; and Advanced Programs tasks funded by the Office of Space Flight. Summary sections describing the role of the Johnson Space Center in each program are followed by one-page descriptions of significant projects. Descriptions are suitable for external consumption, free of technical jargon, and illustrated to increase ease of comprehension.</p>					
17. Key Words (Suggested by Author(s)) Research and Technology R&T RTOP Advanced Programs			18. Distribution Statement Unclassified - Unlimited Subject Category 99		
19. Security Classif. (of this report) Unclassified		20. Security Classif. (of this page) Unclassified		21. No. of Pages 72	
				22. Price*	